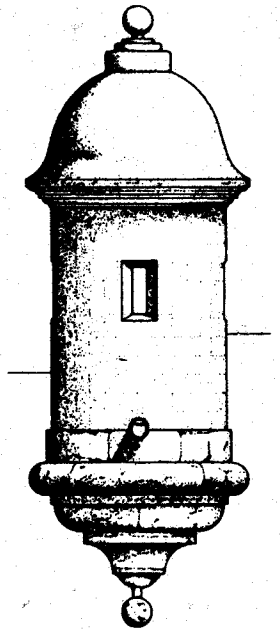
THE FORTIFICATIONS OF SAN JUAN NATIONAL HISTORIC SITE

Volume I



HISTORIC STRUCTURE REPORT

Summaries
Conditions Survey
Recommendations
Glossary
Bibliography
Selected Historic Drawings
Appendices

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For the:
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PREFACE

The historic structure report for San Juan National Historic Site was conceived in 1985 by the Southeast Regional Office of the National Park Service as a part of a "Proposed General Master Plan for the 500th Anniversary Celebration of the Discovery of the Americas" which will be held in 1992. The preparation of the report was a joint effort by the Historic Preservation Center (now the Building Conservation Branch of the North Atlantic Region, National Park Service); the Center for Preservation Research of the Graduate School of Architecture, Planning and Preservation at Columbia University; and, the Historic American Buildings Survey of the National Park Service. The project was funded and coordinated by the Southeast Regional Office of the National Park Service.

We are especially grateful for the interest and assistance supplied by the staff of the San Juan National Historic Site, and to the Park Superintendent, W.P. Crawford. We also wish to acknowledge the assistance and understanding provided by Billy Garrett, Regional Historical Architect of the Southeast Region. Special recognition is deserved of the late park historian Ricardo Torres-Reyes and Chief Historian of the National Park Service Ed Bearss, whose writings were used extensively in the research of this report. Lastly, we wish to express our great appreciation for the unceasing efforts of our editor, Judith Quinn.

San Juan National Historic Site is a World Heritage Site. As such, it is a unique area of great architectural and historical importance, not only to our country, but to the world. The following study has been done to provide a better understanding of what is there, how it developed, and what issues need to be addressed in the future. It is hoped it will be used as a guide in the preservation of this world class monument.

I. SUMMARIES

RESEARCH METHODOLOGY

The preparation of this Historic Structure Report for the San Juan National Historic Site took place over a five year period: from 1986 through 1991. The features included in this report are; San Cristóbal and its outworks, el Morro, the City Walls, and cultural landscape of el Morro. The project was funded and coordinated by the Southeast Regional Office of the National Park Service, Atlanta, Georgia. Four organizations worked jointly on the project. Three of the organizations are within the National Park Service and worked under contract with the Southeast Regional Office: the Historic Preservation Center (HPC, now the Building Conservation Branch of the Cultural Resources Center), North Atlantic Regional Office (NARO), in Boston, Massachusetts; the Division of Planning and Design also of NARO; and the Historic American Buildings Survey, Washington, D.C. (HABS). The Center for Preservation Research (CPR) of the Graduate School of Architecture, Planning, and Preservation at Columbia University, New York, New York, worked under a cooperative agreement with the Southeast Regional Office. Judith Quinn, Architectural Conservator, HPC, edited the report.

The Historic Structure Report is divided into four volumes. The contents of each volume are outlined below.

Vol. I: Summaries of the historical and structural development of San Cristóbal, el Morro, the City Walls, and the cultural landscape of el Morro. Conditions and deterioration phenomenon of the fortifications. Recommendations for preservation treatments. Appendices. Glossary. Reproductions of historic architectural drawings. Bibliography.

Vol. II: San Cristóbal (twenty unit chapters).

Vol. III: El Morro. City Walls. Materials used in construction. Cultural Landscape Report.

Vol. IV: Compilation of all drawings executed by HABS of the fortifications.

Preparation of this report entailed the careful examination of all structures in the field. Extensive notes and sketches were made concerning configuration, materials of construction, and conditions. HABS drawings were used as much as possible to record this information. Documentation included taking black and white photographs and color slides of each structure. Materials were examined <u>in situ</u> and samples extracted (primarily mortars and finishes) and brought back to the HPC and CPR laboratories for analysis.

Much of the historical research was carried out concurrently with the field work periods of the project. Photocopies and microfilms of documents and copies of historic drawings from archives in Spain and Washington, D.C. were used for this report; these dated both to the Spanish and American tenures. The archives of the San Juan NHS were likewise used for historic information, especially photographs and documents postdating 1898.

Historical information was also provided by Juan Blanco, CPR, who was contracted to prepare a comprehensive history of the fortifications of San Juan. His report, "A Study of the Morphological Structure of the Systems of Fortifications of San Juan de Puerto Rico with a Special Emphasis on the Development of the 'Frente de Tierra de San Cristóbal'" is in the collection of the Southeast Regional Office.

Careful assessment of field investigation, results of material analyses and examination of all available archival information enabled the determination of the structural evolution of the fortifications.

San Cristóbal

The documentation of San Cristóbal was carried out from 1986 to 1988. HPC and CPR worked jointly on this site. The members of the HPC team were: E. Blaine Cliver, Chief; Richard Crisson, Historical Architect; and Barbara Pearson Yocum, Architectural Conservator. The members of the CPR team were: Frank Matero, Director; Joan Berkowitz, Architectural Conservator; Marie Ennis, Graduate Student Intern; and Shelley Sass, Architectural Conservator. Jana Gross, Architectural Technician, HPC, prepared many of the graphics for this section of the report.

The fortress was subdivided into component units which were each assigned to members of the HPC and CPR teams by the Southeast Regional Office. Each unit was given a structure number. (These numbers were especially useful for labeling the material samples that were extracted during the course of research.) The original assignation of structure numbers are listed below. The structure numbers do not necessarily correspond to the chapter numbers in Volume II.

01 Main Gate (Entrada Principal), CPR
02a North Casemates (Casamatas del Norte), HPC
02b Guardhouse at the North Casemates (Casa de la Guardia), HPC
03 Cavalier (Caballero), HPC
04 Plaza (Plaza de Armas), CPR
05 Chapel (Capilla), HPC
06 Bath & Well Houses, CPR

07 Officers' Quarters and Cisterns (Pabellón del Gobernador & Cisterna), CPR
08 South Gate (Porta del Socorro), CPR
09 Troops' Quarters (Cuarteles), HPC
10 North Bastion, Curtain, and South Bastion (Baluarte del Norte, Cortina, Baluarte del Sur), CPR
11 Fort of the Point (Fuerte del Espigón), HPC
12 Saint Teresa Battery (Batería de Santa Teresa), CPR
13 San Carlos Ravelin (Revellín de San Carlos), HPC
14 Trinidad Counterguard (Countraguardia de la Trinidad), CPR
15 Fort of the Princess (Fuerte de la Princesa), HPC
16a Fort of the Fan (Fuerte del Abanico), HPC
16b Guardhouse at El Abanico, HPC
16c Northeast Gate at El Abanico, HPC
16d South Gate at El Abanico, HPC
T-1 Tunnel 1, HPC
T-2 Tunnel 2, HPC
T-3 Tunnel 3, HPC
T-4 Tunnel 4, HPC
T-5 Tunnel 5, CPR
T-6 Tunnel 6, CPR

Each chapter is further subdivided into three sections: Description, Structural Evolution, and Condition. For the purpose of this study, the structural evolution of each unit of San Cristóbal is divided into six periods.

1625-1765: Dutch invasion of San Juan (1625)
1765-1809: Major development of fortifications
1809-1837: Span of five gubernatorial terms, Salvador Meléndez to Miguel de la Torre
1837-1868: Span of 17 gubernatorial terms, Francisco Prieto to Julían Juan Pavía
1868-1898: Span of 24 gubernatorial terms, José Sanz to Manuel Macías Casado
1898-1987: American Occupation

El Morro

The documentation of el Morro began in 1988 and continued through 1990. Both the HPC and CPR were involved. The members of the HPC team were: E. Blaine Cliver, Chief; Judith Jacob, Architectural Conservator; Walter Sedovic, Historical Architect. The members of the CPR team were: Frank Matero, Director; Joan Berkowitz and Marie Ennis, Architectural Conservators; and Paul Baumgarten, Dierdre Brotherson, Thomas Giordano, and Mark Lam, Graduate Student Interns.

The structural evolution and materials used in the construction of el Morro were documented by HPC and the

conditions documented by CPR. HPC used a video camera as an added documentary aid. An archaeological dig conducted in the main moat in 1989 by the Southeast Regional Office under the direction of E. Blaine Cliver revealed additional vital information.

The structural evolution is divided into five major periods.

1540-1600:	Conception
1600-1765:	Development
1765-1790:	Transformation
1790-1898:	Modification
1898-1958:	New ownership

The description and structural evolution of the lighthouse is contained as a separate portion of the el Morro section.

CPR recorded the existing conditions graphically. Aerial photographs from the U.S. Army Corps of Engineers in Jacksonville, Florida were reproduced on 24 by 36 inch sheets of mylar. Graphic symbols of conditions were then press-applied to the sheets. These are not included in this report but are located in the HPC office.

City Walls

The study of the City Walls occurred concurrently with the study of el Morro. Both HPC and CPR were involved with this study. Richard Crisson, Historical Architect, was the member of the HPC team. THe members of the CPR team were: Frank Matero, Director; Marie Ennis, Architectural Conservator; and Paul Baumgarten, Thomas Giordano, Mark Lam, and David Wessel, Graduate Student Interns.

The structural evolution of the City Walls, their present configuration, and a brief description of their condition was documented by HPC. Materials were examined <u>in situ</u>; no materials were extracted for laboratory analysis. For this section, the structural evolution is divided into centuries, from the sixteenth to the twentieth.

CPR recorded the existing conditions of the City Walls graphically, in the same manner as el Morro. Standardized "embrasure sheets" were used to supplement information provided on the mylar sheets. These are located in the HPC office and are not included in this report.

Cultural Landscape

The Cultural Landscape Report for el Castillo de San Felipe del Morro was prepared for the Southeast Region (SERO) by the Cultural Resource Center (CRC) and the Division of Planning and Design of North Atlantic Region (NARO). It exists both as a part of the San Juan HSR and as a separate report. The CLR was written by a team from NARO consisting of Richard Crisson, Historical Architect; Robert Holzheimer, Landscape Architect; and Marjorie Smith, Landscape Architect. The project was directed by SERO, working cooperatively with the Preservation Assistance Division of the Washington Office (WASO), San Juan National Historic Site, and the Puerto Rico State Historic Preservation Office (PRSHPO). The Commonwealth of Puerto Rico initiated the landscape study, and the Office of the Governor agreed to partially fund the CLR.

The documentary research for the CLR began in November 1990, although many other documents and plans were previously collected (beginning in June of 1986) for the other sections of the San Juan HSR. The Task Directive for the CLR clearly stated that the report would be based on the known and collected documents. The CLR team spent additional research time gathering new sources and other historic plans of the Esplanade not previously used. The task of writing the CLR began in the fall of 1990. In accomplishing the work on this report, the team is grateful for the continued assistance supplied by the Superintendent and staff of SAJU NHS. In addition, the authors acknowledge the assistance of the Cultural Resources staff at SERO and the cooperation provided by the staff of the PRSHPO.

In order to evaluate the site integrity and provide appropriate recommendations, the following CLR methodology was applied: research, analysis, and recommendation. The first step was collecting and reviewing information regarding the evolution of the Esplanade. The investigation included both documentary research and field survey work. The CLR documented the historic views (vistas) to and from the land side of el Morro and across the Esplanade. The second step compared existing conditions with landscape data from the various periods of historic significance to determine what remained from these periods. The individual features were grouped into seven basic components: circulation, structures, land form, vegetation, small-scale features, utilities, and views. The third step developed recommendations that retain the Esplanade's integrity, are consistent with its significance and programmed use, and can serve as general management guidelines.

Documentary data and analysis in the report discusses the landscape within three time periods: Period I - Spanish Occupation, 1540-1898; Period II - U. S. Occupation, 1899-

1961; and Existing Conditions. In addition, the CLR includes an evaluation of significance and integrity and a recommended rehabilitation plan.

Materials

The study of materials used in the fortifications was carried out from 1987-1990 by E. Blaine Cliver, Chief, and Judith Jacob, Architectural Conservator, HPC. This section of the report is divided into five categories: Masonry, Wood, Metal, Glass, and Bitumen.

Conditions

The conditions of the fortifications were documented during the field work phases of the project by both the HPC and CPR teams. The information gathered has been assembled and summarized for this section by Joan Berkowitz and Judith Jacob, Architectural Conservators, HPC. General deterioration phenomenon are discussed, as well as types of deterioration specific to certain areas, features, or materials.

Recommendations

Recommendations for preservation treatment were discussed in 1990 by Billy Garrett, Regional Historical Architect, SERO, and the HPC staff involved in the project: E. Blaine Cliver, Chief; Joan Berkowitz, Judith Jacob, and Barbara Pearson Yocum, Architectural Conservators; and Richard Crisson, Historical Architect. This section of the Historic Structure Report was written by E. Blaine Cliver, Chief, Judith Jacob and Joan Berkowitz, HPC. The section covers both general and specific preservation treatments.

Measured Drawings

Extensive documentation, including large format photography and measured drawings, was undertaken by HABS in the 1950s, 1960s and 1980s. Despite these projects, some areas of the fortifications remained unrecorded. For example, the Chapel and el Caballero at San Cristóbal were finally drawn in the summer of 1989 and annotations to the drawings of el Morro continued into 1990.

HABS documentation of the San Juan fortifications therefore spans from 1958 to 1990. See Volume IV of this Historic Structures Report for an explanatory introduction and a complete set of the drawings themselves.

ADMINISTRATIVE DATA

San Juan National Historic Site (SAJU NHS) is located in San Juan, the capital of Puerto Rico. The Commonwealth of Puerto Rico is a self-governing island in the Caribbean, in permanent union with the United States of America. SAJU NHS comprises the principal fortifications associated with the city, commonly known as Old San Juan. It encompasses five major areas that are the remnants of Spanish and American military fortifications dating from as early as the mid-1500s. These are the Fuerte de San Cristóbal, Castillo de San Felipe del Morro, the City Walls, the Esplanade of el Morro, and el Cañuelo. All of the fortifications are on the island, or islet, except for the detached unit on Cabras Island, known as el Cañuelo. All of the fortifications are covered by this historic structure report with the exception of the four quarters buildings at San Cristóbal, and el Cañuelo. The 615-acre Islet of San Juan is connected by bridges and causeways to the metropolitan area of San Juan. Old San Juan's historic district is today an extremely dense urban center, consisting predominantly of mixed commercial and high-density areas with little open space.

Administrative History

Puerto Rico was ruled by the Spanish until October 18, 1898, when it became a commonwealth in union with the United States. The old Spanish fortifications were then transferred to the jurisdiction of the United States Department of the Army. Public interest in the ancient military sites commenced several decades later, in 1934, following a visit by Eleanor Roosevelt. A report written later that year for the Department of the Interior supported preservation of the fortifications as a park. The report stated in part:

> Situated upon these Governmentally held lands are old walls and forts, dating from the eighteenth century [sic], and built by the Spanish Conquistadores, which perhaps represent the most important system of fortifications, as well as the highest development of the art of fortification construction attempted by the Conquistadores in the Western world. . . .
>
> The preservation of these ancient structures will not be difficult or costly, but it will have to be placed in skilled hands, and supervised by sympathetic and professionally trained personnel. It will also be necessary to reclaim the ground upon which they are situated . . . in order that the old fortifications may be placed in an appropriate and dignified setting.

> Otherwise, the inspirational value of these inheritances from another age will be only partially realized, if not entirely lost.[1]

It was not until 1949, however, that SAJU NHS was established by the Secretary of the Interior as authorized by the Historic Sites Act of 1935. The management of the site was outlined in a cooperative agreement between the Secretary of the Interior and the Secretary of the Army who retained ownership of the fortifications. The significance of the area was described as follows in the establishment order that was published in the Federal Register:

> The ancient fortifications of San Juan, Puerto Rico, particularly the massive masonry works of El Morro and San Cristóbal and their connecting walls, are outstanding monuments of the past, possessing exceptional historical and architectural interest for the Nation, and have been declared by the Advisory Board on National Parks, Historic Sites, Buildings, and Monuments to possess exceptional importance as commemorating the history of the United States . . .[2]

> The areas designated as part of the historic site were "the fortresses of el Morro and San Cristóbal, Casa Blanca[3], and el Cañuelo on Cabras Island, including the areas shown on the diagram . . . ."[4]

National Park Service (NPS) involvement with SAJU NHS commenced upon the signing of the previously described cooperative agreement in 1949. The agreement stated in part that the NPS would provide guide and lecture services, museum exhibits, signs, markers, etc., needed for the exhibition of the site to visitors within the limits of available appropriations. The NPS would also prepare plans for the development of other visitor facilities, provide technicians to review work plans for historically important sections of the fortifications, and support requests to the Congress for

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[1] John L. Nagle, "Report on Park Development and Tourist Trade Possibilities: Island of Puerto Rico," December 10-18, 1934. Original manuscript at San Juan NHS Archives.

[2] Federal Register Document 49-1402 dated February 25, 1949.

[3] Casa Blanca is a fortified house that was built ca. 1520 for the family of Juan Ponce de Leon. It is not included in this historic structure report.

[4] Ibid. These "areas" were probably the City Walls.

funding of preservation work. A NPS Superintendent was employed at the site as early as 1951.[5]

Ownership of the fortifications comprising SAJU NHS was transferred from the Department of the Army to the Department of the Interior in September 1961. Included in this transmittal were the Fuerte de San Cristóbal, the Castillo de San Felipe del Morro, most of the City Walls, and el Cañuelo. Portions of the City Walls not conveyed to the Department of the Interior were three short segments that became the property of the Commonwealth of Puerto Rico; these were located on the south side of the city near the Governor's mansion, la Fortaleza. Casa Blanca, another component of the National Historic Site, remained the property of the Department of the Army at this time.

The historical importance of SAJU NHS was reaffirmed on October 15, 1966, when it was listed on the National Register of Historic Places.[6]

The boundaries of the SAJU NHS were changed by a Cooperative Agreement between the Department of the Interior and the Commonwealth of Puerto Rico dated September 29, 1976.[7] In this agreement it was decided that the Esplanade of el Morro, known as Parcel A, would become a part of the National Historic Site.[8] It was also decided that an adjacent area known as

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[5] Edwin C. Bearss, Historic Structure Report Historical Data Section: San Juan Fortifications 1898-1958 (San Juan: U.S. Department of the Interior, NPS, 1979), pp. 379-381 & 388.

[6] The lighthouse at El Morro is also included in a thematic nomination to the National Register, "Lighthouse System of Puerto Rico," that was accepted in 1981. A revised nomination was prepared June 12, 1973 by architect Fred C. Gjessing and Chief Park HIstoric Loretta Schmidt.

[7] "Cooperative Agreement Between The United States Department of the Interior And The Commonwealth of Puerto Rico Concerning The Preservation, Development, Maintenance And Utilization of Certain Lands In Connection With The San Juan National Historic Site," signed September 29, 1976. The agreement is included in the "General Management Plan" for San Juan NHS dated December 1984 as Appendix D.

[8] Parcel A was declared surplus property by the Department of the Army in 1966 at which time it was conveyed to the Department of the Interior. The Department of the Interior in turn conveyed Parcel A to the Commonwealth of Puerto Rico on March 31, 1967. Administration and management of the site, however, was the responsibility of the National Park Service. Jurisdiction of the

Parcel B, and of which Casa Blanca is a part, would not be included within the boundaries of the National Historic Site.[9]

SAJU NHS, along with La Fortaleza, was nominated to the World Heritage List of the United Nations Educational, Scientific and Cultural Organization, in 1982; it was accepted on January 23, 1984.[10] Not included in this nomination were the Esplanade of el Morro (Parcel A) and Casa Blanca.[11] The significance of the fortifications of Puerto Rico, including SAJU NHS, is described in the nomination as follows:

> The fortifications of San Juan and the other mighty redoubts built by Spain in the Americas are premier physical evidences of the epic imperial struggles that permanently fixed the destiny of the Americas. They are key monuments of the era when the Caribbean was the cockpit of international maritime rivalry and its islands played a part of almost undue importance in world strategy that was particularly international in its happenings. . . . In their engineering art, the Spanish forts girdling the Caribbean are manifestations of the architectural-engineering and historical heritage of the Old World and the New. . . . The defenses of San Juan are a well-preserved element in this grand system. . . . These fortifications are eminent physical reminders of Spain's past conquest and political dominion in the Caribbean and of the epic struggle she conducted to maintain her Empire in the Americas. . . . In this century, however, these fortifications have been transformed into potent symbols of the cultural ties that link the Hispanic World. . . . San Juan's forts remain as the cultural patrimony of the Puerto Rican people,

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El Morro moat and counterscarp wall within Parcel A were transferred from the Commonwealth of Puerto Rico to the Department of the Interior on January 28, 1970. Similarly, ownership of the Guardhouse in Parcel A was transferred to the Department of the Interior on March 29, 1984.

[9] Parcel B was also conveyed from the Department of the Interior to the Commonwealth of Puerto Rico on March 31, 1967. It is administered by the Institute of Puerto Rican Culture.

[10] The nomination is entitled, "The Historic Fortifications of San Juan: La Forteleza and San Juan National Historic Site." La Forteleza, the Governor's mansion, is under the jurisdiction of the Commonwealth of Puerto Rico.

[11] Parcel A had been added to the San Juan National Historic Site and Casa Blanca had been deleted in the Cooperative Agreement of 1976.

while possessing a meaning even for nations who have striven to control or influence the Hispanic peoples. . . . They form, individually and collectively, for all these reasons, part of the universal historical heritage of humanity.[12]

Three special use permits are currently in effect at SAJU NHS. One allows the Government of Puerto Rico to use the bombproof building (Building 213) in the moat at San Cristóbal. The second grants the Ports Authority of Puerto Rico the use of the World War II fire control station at el Caballero at San Cristóbal. The third permits the United States Coast Guard to operate the lighthouse at el Morro. In addition, a cooperative agreement exists between the NPS and the United States Army Corps of Engineers to "relieve dangers to the historic resources arising from the action of the sea."[13]

Management Issues

SAJU NHS is administered and managed by the National Park Service of the United States Department of the Interior. It is represented in the NPS List of Classified Structures by several numbers as follows (elements marked by an asterisk (*) are not included in this HSR):

Element	LCS Number
San Cristóbal	02171
San Cristóbal Quarters	
Building 1*	06070
Building 2*	06072
Building 3*	06073
Building 4*	06074
San Cristóbal Outworks	
San Carlos	06066
La Trinidad	"
Great Moat	"
Santa Teresa	06067
La Princesa	"
El Abanico	01270
El Morro	01275
City Walls	

[12] World Heritage List Nomination, 1982.

[13] World Heritage List Nomination, 1982, p. 3.

North Wall	06065
South Wall no. 1[14]	06068
South Wall no. 2[15]	06069
El Cañuelo*	06075

All of the classified structures listed above have been categorized as management category "A" except the quarters buildings at San Cristóbal that are management category "B". The NPS defines category "A" structures as those that "must be preserved and maintained," while category "B" structures "should be preserved and maintained."[16]

Treatment of the structures at SAJU NHS is further defined by two planning documents: the San Juan NHS General Management Plan, dated December 1984 and approved September 1985; and, the "Resources Management Plan and Environmental Assessment" dated ca. 1985. The General Management Plan states that the general treatment approach will be as follows:

> The National Park Service will preserve the San Juan fortifications in their existing form, retaining as closely as possible their appearance between 1949 and 1961, the period during which the facilities were last used for military purposes.[17]

The rationale for this approach is also explained in the General Management Plan:

> The fortifications of San Juan must be viewed as a historic district that has evolved over time . . . . Over the centuries of construction and use, the fortifications have remained one of the finest examples

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[14] "South Wall no. 1" is called the west wall in this report. It is defined by the LCS to be 2,550 feet long, running from just south of el Morro up to, but not including, San Juan Gate.

[15] "South Wall no. 2" is called the south wall in this report. It is defined by the LCS to be 800 feet long, running from San Juan Gate to las Palmas Bastion.

[16] "Cultural Resources Management Guideline NPS-28," Release No. 3, August 1985.

[17] Final General Management Plan/Environmental Assessment, San Juan National Historic Site (U.S. Department of the Interior/National Park Service, Dec. 1984, approved September 1985), p. 26.

> of coastal and land defense systems in the world. As a new technology was developed or a need was identified, the fortifications were changed. Each of these changes was a product of its time, and each served a particular need in the overall defense mission. Therefore, the final result of these changes should be preserved so that the whole story can be told to the millions of visitors who come each year.[18]

The "Resources Management Plan" concurs with this preservation philosophy, stating:

> The National Historic Site is to retain the appearance of the structures to reflect conditions at the time they were transferred to the National Park Service by the Department of the Army in the years between 1949 and 1963 [sic].[19]

Specific treatment guidelines are also detailed in the General Management Plan:

> Missing historic fabric will not be reconstructed except when it is determined through the preservation maintenance program . . . that reconstruction is necessary to ensure structural stability of the fortifications.
>
> No physical alterations will be undertaken to provide for adaptive use of the casemates or other interior spaces, or to provide for handicapped visitor access or for visitor safety, if it is determined that such actions will impair the significant architectural features or structural system of the fortifications.
>
> Interior spaces will generally not be restored unless it is absolutely necessary to help convey an interpretive theme.[20]

The General Management Plan acknowledges the fact that the NPS has not followed this preservation philosophy in the past, stating "past restoration and removal of materials dating from the historic period (1539-1961), particularly at San Cristóbal, has created a configuration of the fortifications that never

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[18] Ibid., p. 26.

[19] "Resource Management Plan and Environmental Assessment for San Juan National Historic Site," (U.S. Department of the Interior/National Park Service, 1985?), p. 4.

[20] General Management Plan, p. 26.

existed historically." More specifically, the treatment approach of the NPS in the 1960s and the 1970s had been to repair and restore selected structures to their original, as-built appearance. For example, the Officers' Quarters building at San Cristóbal was restored to its exterior appearance of 1775, while its south wing built in ca. 1861 has been retained as public rest rooms. There is no provision in either the General Management Plan or the "Resource Management Plan" for rectifying this situation.

This historic structure report proposes a revision to the treatment approach at SAJU NHS as stated in the planning documents referenced above. It is recognized that there are five major periods of significance at the site. These are:

Spanish I	ca. 1539-1760	Initiation of harbor defenses at el Morro, harbor walls and city gate;
Spanish II	ca. 1760-1835	Period of major development at el Morro, San Cristóbal, north wall;
Spanish III	ca. 1835-1898	Modernization & rehabilitation of defensive system and outworks;
American I	ca. 1898-1940	Construction of the el Morro Lighthouse;
American II	ca. 1940-1961	Construction or the World War II harbor defense system.

It has been determined that the American periods do not include any other resources that are known to be significant and to merit preservation. By this definition, features that were reconstructed by either the Army or the NPS (such as some of the sentry boxes) are considered to be "non-historic" or "non-significant." The remnants of Fort Brooke are also considered to be insignificant and not worthy of preservation.

It is recommended that the treatment at SAJU NHS be a combination of preservation, restoration and rehabilitation. Those elements that should be preserved are all existing fabric that dating from the Spanish periods, the lighthouse at el Morro, and the American harbor defense system from World War II.

Limited restoration work may be undertaken on significant elements by removing features that are not historic and by reconstructing missing historic features for which adequate documentation exists. Lastly, those features that are

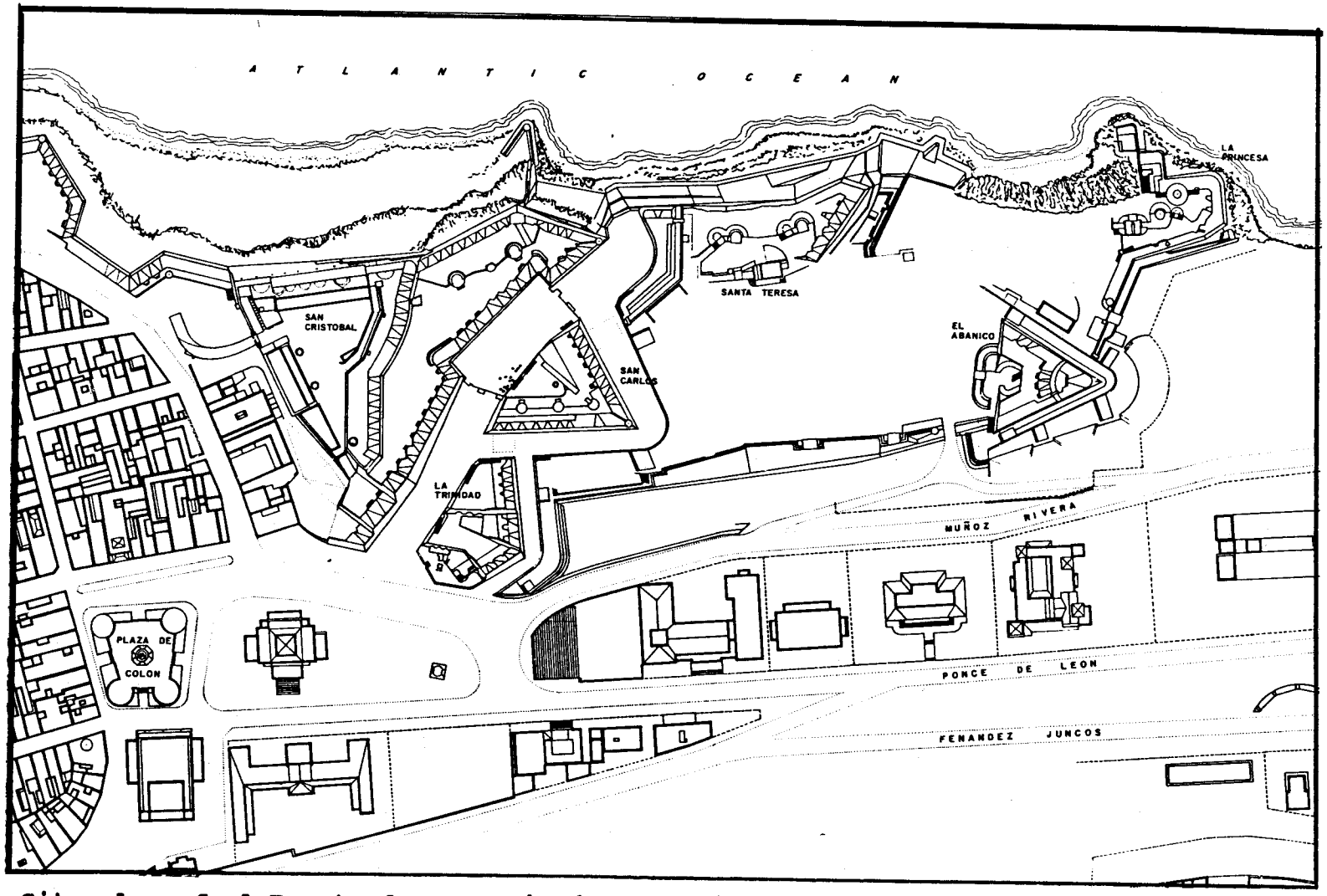
determined to be of lesser significance may be rehabilitated for use by visitors and by NPS administration.

If it is decided to adopt this revised treatment approach at SAJU NHS, it will be necessary to amend the existing General Management Plan.

A SUMMARY OF
EL FUERTE DE SAN CRISTOBAL

Fuerte de San Cristóbal is located at the northeast corner of the walled city of old San Juan. It is composed of two parts: the main fort and the outworks. (See figure on page 22.) The main fort was constructed in 1634 and was substantially rebuilt between 1766 and 1785 when it became a component of the east city walls. The highest and most prominent feature, el Caballero (the Cavalier), rises approximately 148 feet above sea level. The outworks, five fortified units to the east of the main fort, were built between 1769 and 1783. All five of the outworks, or portions thereof, survive today. San Cristóbal and its outworks cover an area of about 27 acres. San Cristóbal was named in the seventeenth century for the large hill San Cristóbal (Saint Christopher) on which it was built. San Cristóbal's function then, and in later centuries, was to provide defense for the city of San Juan from the eastern land and northern sea approaches. The defensive capabilities were tested in 1797 when Britain's Sir Ralph Abercromby's invasion of San Juan was successfully repelled by the Spanish. One hundred years later, in 1898, the first shot of the Spanish-American War was fired from San Cristóbal. Although several additions and alterations have been made in the nineteenth and twentieth centuries, San Cristóbal today preserves much of its eighteenth-century character.

The initial construction of the redoubt (small fort) known as San Cristóbal was begun in 1634 as part of the project to surround the city of San Juan with a fortified wall. This was in response to the Dutch invasion in 1625 in which the city was burned and ransacked, leaving its citizens destitute. The design for the redoubt is believed to have been sent from Spain. Early construction of San Cristóbal and the city walls was under the direction of Juan Bautista Antonelli whose father redesigned the existing Castillo de San Felipe del Morro in 1589. The earliest known plan of San Cristóbal, by Venegas Osorio, is dated 1678. Major features in the plan were a semi-circular Caballero that contained a cistern, a demi-bastion on the west side of el Caballero, a North Bastion (Baluarte del Norte), a South Bastion (Baluarte del Sur), the Curtain (Cortina) connecting the two bastions, a dry moat, and a post to the north, Fuerte del Espigón (Fort of the Point). All of these features exist today with the exception of the demi-bastion that was later incorporated into the Plaza de Armas. Because San Cristóbal was enlarged and heightened in the eighteenth century, many of the early features were incorporated into later construction. Original features that are visible today are; the east curved wall of the Caballero, the north face of the Caballero that is now the south wall of



Site plan of el Fuerte de San Cristóbal and immediate vicinity of San Juan. (HABS drawing 1984. Based on Capt. Hodges, U.S. Corps of Engineers, General Plan, March 1899.)

Tunnel 3, the north face of the fort that is now the south wallof Tunnel 1, a passage to the main moat that is now the "dungeon" of Tunnel 1, and the north post known as el Espigón.

Spanish military records indicate that San Cristóbal deteriorated rapidly after it was constructed due to the use of poor materials, inferior workmanship, and the harsh marine environment. Reports of poor construction were made to Spain as early as 1636. A survey by a military engineer in 1731 found that all the fortifications of the city, including San Cristóbal, were in a state of complete decay. Some repair work was carried out in 1749 such as the building of two buttresses to provide additional to support the North Bastion.

The year 1765 was the beginning of the complete modernization of San Cristóbal. The primary objective of this modernization project was to make the fort the backbone of an improved and enlarged defense system for the City of San Juan, particularly the eastern defenses. At this time, Field Marshall Alexander O'Reilly was dispatched to Puerto Rico by the King of Spain to assess the conditions of the fortifications and to prepare a revised defense project for the city. Thomas O'Daly, Chief of the Military Engineers, was commissioned to prepare a report and two sets of plans: one to show the existing state of the fortifications, and the other to show the proposed modernization project. These two men, aided by a group of collaborators, completed the assignment in less than two months. The prepared documents were summarily sent to Spain where the project was approved by a military board and by King Charles III of Spain. Thomas O'Daly was chosen as the supervisor for the project. Assisting him were three engineers (Antonio Panon, Pablo Castello, and Juan Francisco Mestre) and two master architects (Diego Ramos and Antonio Sein). Construction work began on January 1, 1766, two months before the approved project was received in San Juan on March 10, 1766. The work crews were composed of soldiers and foremen from the Toledo Regiment that garrisoned the city, day laborers, outcasts, prisoners, and slaves.

The modernization project was in progress for twenty years, lasting through 1785. The work was divided into three major phases: 1766-69, 1769-73, and 1773-85. The first phase involved improving the old fort and constructing new features. Prior to construction, excavations were first made into the old walls to ensure that they were structurally sound enough to be built upon. Obsolete elements such as an old powder magazine to the south and the demi-bastion to the west were then removed. After this limited demolition, new construction was begun. The floor of the large dry moat, on the east side of the main fort, was deepened. Simultaneously, the adjacent walls of the North Bastion, the Curtain, and the South Bastion were thickened, reinforced, and heightened. The North Bastion

was widened on the north side, the level of the old terreplein was raised six feet, and the terreplein of the Curtain and the South Bastion was raised three feet. New parapets were added to the newly raised Bastions and Curtain, incorporating twenty-three embrasures on the east side and fourteen embrasures on the north side. A new ramp was built on the west side of the old Caballero and a new extension to the north was begun. Three countermining galleries, now referred to as Tunnels 1, 2, and 5, were under construction within the main fort. These long narrow passages could be blown up if the enemy were to gain access to the fort. Tunnel 2 served as the postern, or the main access, between the main fort and the projected outworks to the east. Construction of one of these outworks, San Carlos Ravelin (Revellín de San Carlos), was already begun on the east side of the large dry moat. The work of this phase came to an abrupt halt in January 1769 when a section of wall, the Curtain between the North and South Bastions, collapsed. A plan by O'Daly dated January 15, 1769, summarized the work done to date and the projected work that remained to be executed. Additional documentation of this construction phase is also provided by periodic engineering reports that were required by a royal order issued in October 1768.

The initial work of phase two, 1769-73, concentrated on cleaning up the area of the fallen Curtain. An investigation and careful reexamination of all the old walls in the fort was conducted. It was determined that the failure of the curtain had been caused in part by the use of blind arches and clay within the early walls combined with the great weight of the new construction and the slow infiltration of water. Some of the walls were reinforced and buttressed. New construction atop and below the old walls proceeded with extreme caution. The damaged Curtain was repaired and finally completed one year later, in February 1770. The old Caballero was enlarged by raising its terreplein six feet, by building the second floor of an extension to the north, and by constructing a large wing to the south. Seventeen embrasures were built into the Caballero's parapet, fifteen facing east and two facing north. The north extension of the Caballero, now considered a part of the North Casemates (Casamatas del Norte), housed magazines for the storage of gun powder. The south extension, now known as the Troops' Quarters (Cuarteles), housed five bomb-proof vaults in two levels for artillery and artillery personnel. A circular stair enabled direct access between the vaults and the upper Caballero. Two new passageways, Tunnel 3 and Tunnel 4, enabled communication between the new Plaza and the renovated Bastions and Curtain to the east. Other work involved the final plastering of all the old and new walls both for protection from the weather and to facilitate the collection of rain water to the repaired cistern in the Caballero. The terrain outside of the main fort to the east was leveled to form the glacis. Also substantially finished was a new

outwork, la Trinidad Counterguard (Contraguardia de la Trindad), situated to the south of San Carlos. All the work completed up to February 26, 1773, was documented by O'Daly in a series of plans, profiles, and elevations of all the works.

The last phase of construction, 1773-85, included work on both the main fort and the outworks. Reinforcement of the old walls continued with pilasters added to the wall of the South Bastion. Two new cisterns, composed of bomb-proof vaults, were built beneath the Plaza de Armas on the west side. When filled, it was expected that they would hold sufficient water to support the garrison for five months. Above the cisterns was constructed a one-story structure known today as the Officers' Quarters (Pabellón del Gobernador). Here were housed the guards, the officer in charge of the cleanliness and custody of the fort, and the personnel in charge of distributing water and cleaning the cisterns. Work on the entrance ramp commenced in 1774 and was completed by 1775. Under the ramp were approximately two vaults that may have been used for kitchens to feed the soldiers housed in the Troops' Quarters. Also begun in 1774 but not completed until 1785 were the one-story casemates on the north side of the Plaza that are now known as the North Casemates. This strucuture had nine bomb-proof vaults for use as quarters for one battalion, a kitchen, and a latrine; the terreplein above was intended to provide a defense from north sea approaches. Leveling of the terrain to the east was continued in 1778. The following year, two new outworks, Redoubt No. 1 and Redoubt No. 2, were constructed of earth and fagot (bundles of sticks). These were rebuilt with masonry by 1783 and were renamed Batería de Santa Teresa (formerly Redoubt No. 1) and Fuerte del Abanico (formerly Redoubt No. 2). Santa Teresa was sited along the north coast. Its primary function was to defend el Abanico, a fan battery, situated farther to the east. Also completed by 1783 was another outwork, la Princesa (Fuerte de la Princesa), whose function was to correct the defects of the terrain at the north coast and to the east of Santa Teresa. Finish details completed the work at San Cristóbal such as doors, windows, bridges, palisades, and gates. The existing conditions in 1783 were shown in a plan of San Cristóbal and its outworks dated 1783 by Engineer Juan Francesco Mestre; Thomas O'Daly had died two years earlier, in 1781. Two other plans, dated 1793 and 1795, also documented the state of the completed works.

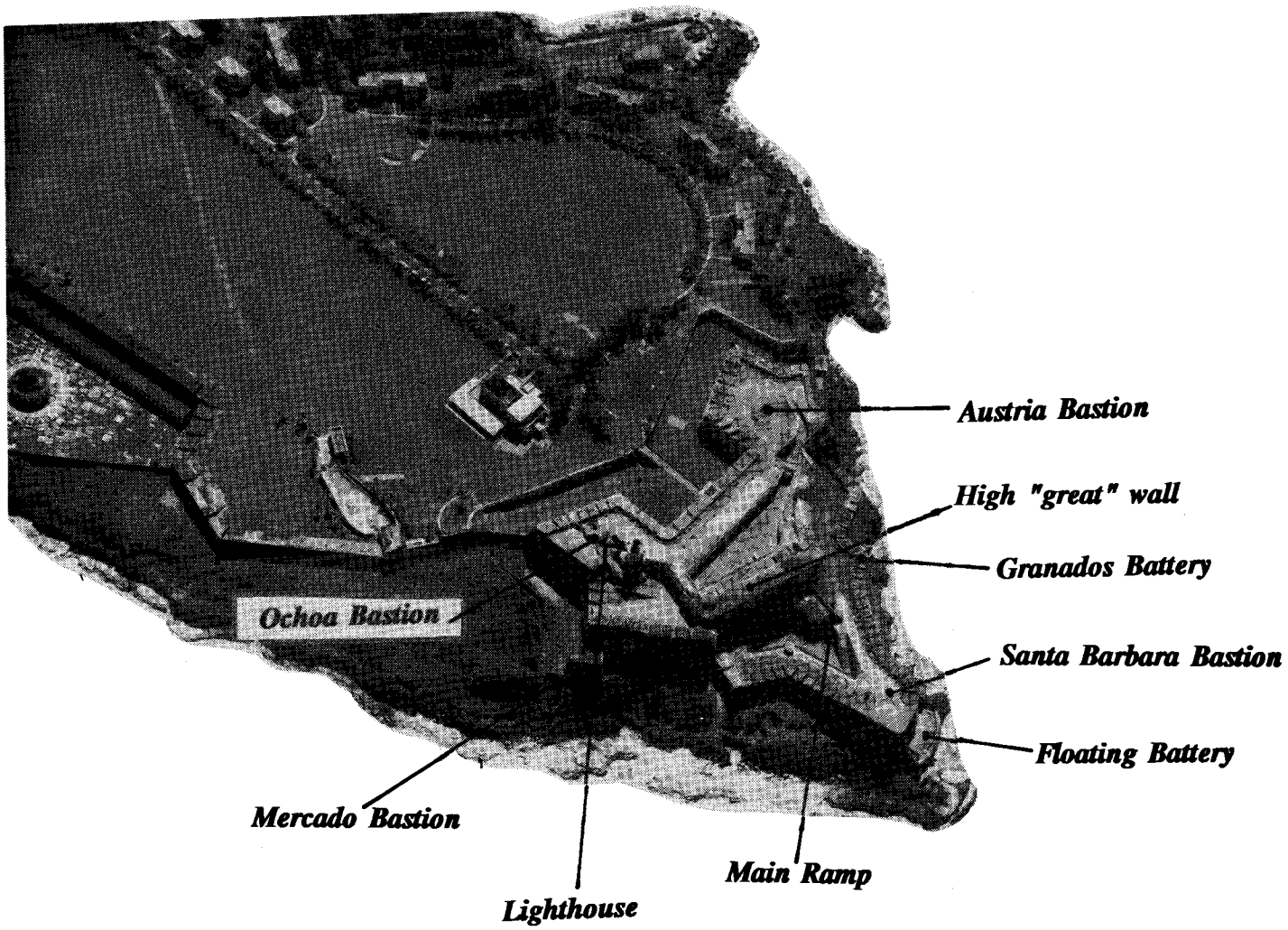
Several alterations and modifications were made to San Cristóbal by the Spanish in the nineteenth century. These changes were documented by a scale model of the fort that was made in 1839, detailed plans and elevations prepared by Manuel Castro in 1861, and specifications for work dated 1896. Projects were completed sometime before 1839 included the construction of a Guardhouse in front of the North Casemates,

enclosing the loggia on the Plaza side of the Officers' Quarters, and building a signal house on the north end of the Caballero. It is unclear if Castro's drawings of 1861 showed existing conditions or proposed new work. Most of the new features that were illustrated, however, appear to have been built. These were; the Chapel on the Plaza, an addition on the north side of the Guardhouse of the North Casemates, a loggia on the Plaza side of the North Casemates, a large addition to the south side of the Officers' Quarters, a bath house in place of one of the Plaza's well heads, and a garden on the Plaza in front of the Officers' Quarters. Extensive alterations were made to the outworks of San Cristóbal during the 1890s. La Trinidad was partially demolished as part of the expansion of the old city of San Juan to the east and south in 1897. Additional changes were made to the other outworks in 1896-97 in preparation for the Spanish-American War. Santa Teresa was modified by the emplacement of two gun positions and an earth-covered field magazine. El Abanico was changed by the installation of a cistern in a portion of its moat, the building of a Guardhouse for la Princesa on the north side of the moat's covered way, and the building of a South Gate and a Northeast Gate, both with sentry boxes. Most altered was la Princesa where four gun emplacements and three traverses with bombproof vaults were installed. Gun positions were also emplaced within the main fort of San Cristóbal on the terreplein of the North Casements, at el Caballero, and at the North Bastion.

American military occupation of the island of Puerto Rico and the fortifications of San Juan commenced in October 1898 after the conclusion of the Spanish-American War. The American military maintained a presence at San Cristóbal through 1961. Alterations during the American occupation included the installation. Fixtures for a new sewer and plumbing system were installed in 1899. Electrical lighting was introduced in 1901. A large housing development for military personnel was erected at la Princesa in 1930, obliterating most of its ca. 1897 features. The late 1930s were characterized by restoration and repair work carried out by the U.S. Army. El Espigón was restored in 1938-39, new roofs were installed on the Chapel and the loggia of the North Casemates in 1939, and some of the badly deteriorated sentry boxes were rebuilt in 1939. A harbor defense system was installed during the World War II years, 1941-45. Two fire control stations were built at el Caballero and the North Bastion, a Joint Operations Center was constructed in the main moat, and several gun blocks were emplaced along the northern edge of the outworks.

San Juan National Historic Site, of which San Cristóbal is a part, was created in 1948. It was not until 1961, however, that the National Park Service (NPS) was given jurisdiction over the site. Since 1961, the NPS has attempted to repair and

restore selected features of the fort to their original appearance. Those features, and the dates to which they were restored, are: the Well Houses on the Plaza (1775), the east loggia of the Officers' Quarters (1775), the Troops' Quarters (1771), el Abanico (1783), the North Casemates (1785), the Chapel (ca. 1861), and the Guardhouse at el Abanico (1896), the South and Northeast Gates at el Abanico (ca. 1896). The problem with this fragmented approach to preservation is that it has created an assemblage of features that never existed historically in their current configuration. For example, even though the loggia of the Officers' Quarters has been restored to its 1775 appearance, the large wing to the south, built in ca. 1861, has been retained for use as public rest rooms. Removed in the mid-1970s were the buildings and roads associated with the 1930 housing project at la Princesa, yet still surviving are the major components of the 1940s harbor defense system. San Cristóbal today retains structural remnants of all its major phases of development, from the seventeenth through the twentieth centuries. However, its major form and character date to the period of its major reconstruction in 1765-85 under the supervision of engineers Thomas O'Daly and Juan Mestre.



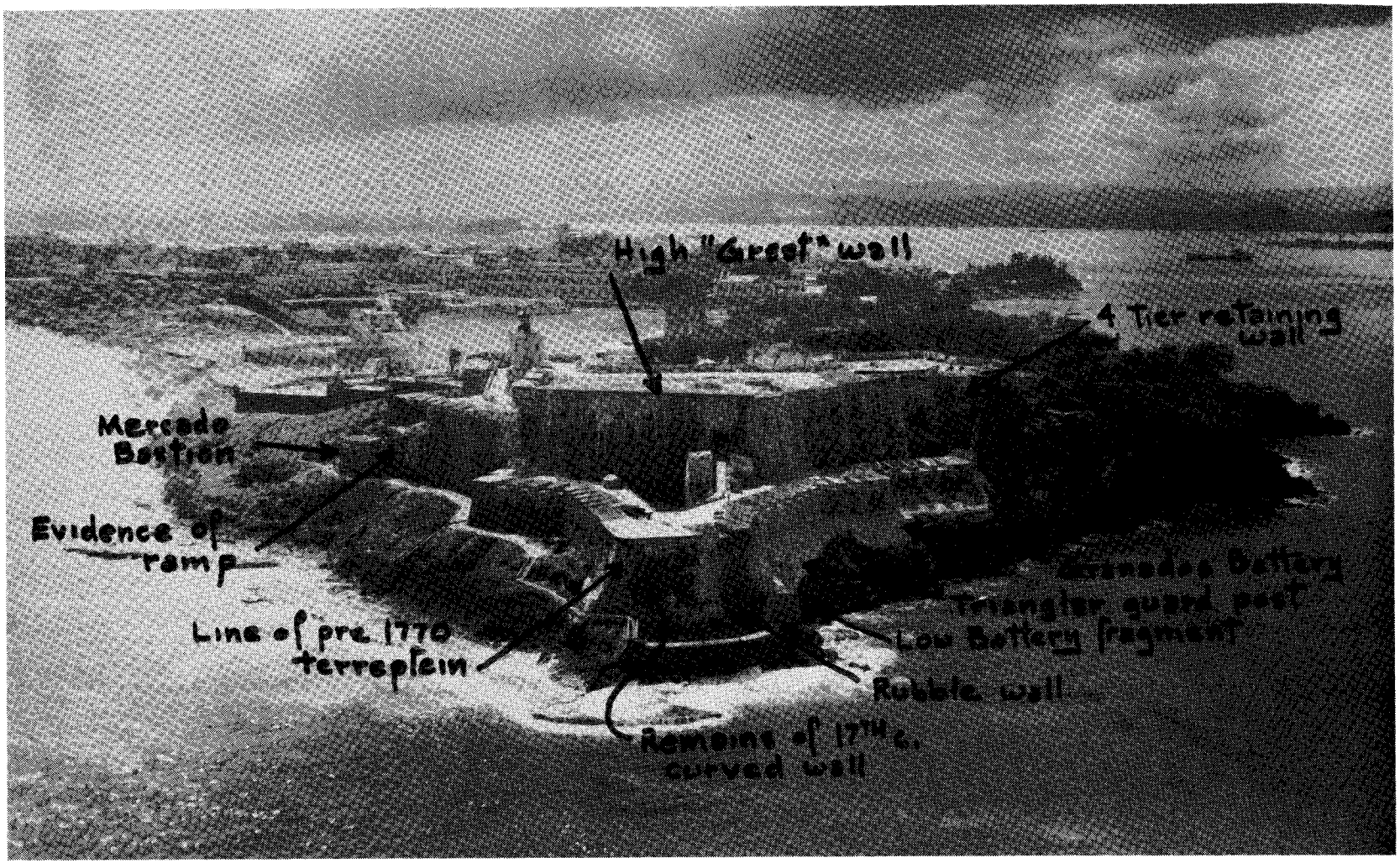
Aerial view of el Morro with features labeled. (Photo, ca. 1960, SAJU Archives, annotated by J. Quinn 1990.)

A SUMMARY OF
CASTILLO DE SAN FELIPE EL MORRO

Shortly after the first fort in San Juan (la Fortaleza, now the Governor's Mansion) was built in the 1530s it was recommended that a second fort be placed at the entrance to San Juan harbor. Approval for the second fort was given in 1539. Named el Castillo de San Felipe del Morro after the reigning king's patron saint, it was first described in 1554. This description stated that a tower, with a lower battery platform, existed at the harbor entrance. Little remains of this early fortification. What does remain can only be seen today from the interior as the above mentioned tower is now located within the toe of the later Santa Barbara Bastion. It is the lower walls of this interior space that date from ca. 1540. The dome over this space is later, possibly as early as the construction of the Santa Barbara Bastion, ca. 1650, or as late as the 1770s. In these lower walls can be seen embrasures for four cannon. The embrasures have been closed in, and over time, two have been used for access to batteries located outside the wall and closer to the water. The embrasure farthest to the left now provides access to the present Water (Floating) Battery that was constructed about 1763.

By the beginning of the seventeenth century (ca. 1600) a high platform had been constructed over the tower and a wall had connected it to a recently constructed Mercado Bastion. Here, terminology begins to cloud the identification of these early descriptions with the remaining physical features. It does not seem likely that the "high platform", referred to in the late-sixteenth century, is the Santa Barbara Bastion. As will be explained, the plans for an expanded el Morro, prepared and laid out by the engineer Antonelli, were executed first at the land defense side. Work at the harbor entrance did not commence until after ca. 1625. It is the plan of Antonelli that eventually becomes the basis for the triangular fortification we see today.

After the departure of Cumberland, who had captured el Morro in 1598, implementation of Antonelli's plan began. By 1602 construction was started on the "hornwork." The hornwork consisted of the two bastions, Ochoa and Austria, a curtain wall connecting them, and a connecting wall to Mercado Demi-Bastion. Two plaques in the present walls of each of these bastions state that the work on the bastions was completed in 1606. However, documentary sources indicate that, owing to a lack of funds, additional work continued in this area for the next fifteen years. A 1625 plan of San Juan showed the hornwork complete. (Remains of the 1602 hornwork were uncovered by an archaeological excavation in May 1990.)



Aerial view of el Morro with features labeled. (Photo ca. 1960, SAJU Archives. Annotated by E.B. Cliver, 1990.)

By 1676, the Santa Barbara Bastion (as shown on a 1742 drawing), seems to have existed. With the construction of Santa Barbara Bastion was built the Low Battery.

The Low Battery, shown below Santa Barbara Bastion on the earliest architectural drawing of el Morro (1742), preceded the present battery in this location. (See Historic Drawings in Volume I of this HSR.) This Low Battery was twice as high as the present Water Battery, and projected farther into the harbor entrance. Evidence for the height of the terreplein (floor) of this earlier battery can be seen in the exterior wall of Santa Barbara Bastion as a change from a scarp (sloping wall) to a vertical rubble wall. The rubble portion of the wall would not have been exposed; therefore, the height of the Low Battery terreplein was at the top of the rubble portion of wall. In addition, a wall fragment of this Low Battery remains above the harbor side of the Water Battery. Access to the Low Battery was from the old tower room, through an embrasure converted into a passageway that passed through the walls to the battery floor level. At the time that this embrasure was opened (it was refilled in ca. 1763) in the seventeenth century, a passage was cut into the floor of the tower room to give more height to the embrasure/doorway. This cut in the floor still can be seen.

Depicted on the 1742 drawing were several buildings on the upper plaza, or Plaza de Armas, including a guard house, troops' quarters and a chapel. At the lower level, the Santa Barbara Bastion (only the toe of what presently exists) with the Low Battery in front, and Granados Battery were shown. Granados Battery seems to have been added at the beginning of the eighteenth century (ca. 1702) to increase the number of cannon on the harbor side of el Morro. As mentioned previously, a fragment of the Low Battery exists to the harbor side of the present Water Battery. Following the line of masonry from this fragment, along the harbor edge to the southeast, one can see the remaining wall of Granados Battery including a small projection (remains of a sentry post). The old wall of Granados Battery now serves as the foundation for the expanded Santa Barbara Bastion wall. On the ocean side, the 1742 drawing showed only a thin masonry wall connecting Mercado Bastion and Santa Barbara Bastion.

In addition to the plan, the 1742 drawing also depicted el Morro in section. By measuring elevations from this section and comparing them to those same elevations in the fort today, it becomes obvious that some terreplein levels within the fort have been increased. This increase seems to have been about 3.5 meters, or 11 feet, in the terrepleins of both Santa Barbara and Austria Bastions. As shown on the 1742 plan, Austria and Ochoa Bastions had orillóns (recesses in the bastion's flanking wall for enfilading the curtain). It was

the corner of the Austria orillón that was found during a 1990 archaeological excavation. Finding this corner allowed the team to date the wall fragment to the seventeenth century, as well as dating the material filling the orillón and the existing wall of the bastion to the late eighteenth century.* During the later half of the eighteenth century, extensive changes were made to both el Morro and San Cristóbal.

In 1765, Field Marshall Alexander O'Reilly proposed vast modifications to the San Juan defenses. Included in the proposal was a plan of San Juan and a written description of the existing fortifications. The 1765 plan showed the present Water Battery configuration, although O'Reilly's written description indicated that the Water Battery had been recently rebuilt. Following the proposals of 1765, work began on the fortress. In 1773 the hornwork was rebuilt by demolishing the seventeenth-century walls and increasing the floor level in the moat. New walls were constructed using the remains of those demolished as a foundation. Most of what can be seen of the hornwork, from the harbor side of Austria Bastion to the east wall of Mercado Bastion, dates from the 1770s.

By the early 1780s, a retaining wall had been constructed across the Ochoa end of el Morro's moat. This wall enabled the moat floor to be raised about three meters (10 feet) at this point, creating a level moat floor across the land front. Ochoa Bastion stepped up in two tiers on the ocean side owing to the steep drop in elevation at this location. The rapid drop in elevation also required that the moat floor slope across the land front and drop even more steeply on the ocean side of Ochoa Bastion. When the hornwork was rebuilt and the terrepleins increased in elevation in the 1770s, Ochoa Bastion retained its two tiers owing to this great change in elevation. However, by 1786 the moat floor on the ocean side of Ochoa Bastion had been increased in elevation, providing more support for the Ochoa scarp. This allowed the lower tier of Ochoa Bastion to be increased in height to the level of the upper tier. The terrepleins of the curtain, and the Ochoa and Austria Bastions were at one level, as seen today.

During the 1770s el Morro's upper plaza achieved its present appearance. Vaulted casemates were constructed around the plaza's perimeter, expanding the width of the curtain

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* The location of the orillón corner enabled the elevation of the orillón floor to be determined with a transit. This dimension corresponded well to the elevation for the floor measured on the 1742 section. Such close correspondence has helped to evaluate the accuracy of the 1742 drawing though corrections were found to be necessary to the scales of the drawing.

terreplein as recommended in 1765. (At least one original casemate door remains, it is on the plaza entrance to the ranger's lunch room.) As part of this work the chapel was built. Also, the magazine vaulting was constructed in order to support the weight of the masonry overburden resulting from the increased elevation of the Austria terreplein. In order to support the weight of the upper plaza construction, and to provide a high platform for placing artillery oriented toward the sea, a great wall was built upon an earlier retaining wall. The construction of this wall was completed in 1776, and included the main ramp leading from the upper plaza to the terreplein of Santa Barbara Bastion. In addition, a large cistern was incorporated into this work below the plaza. A new ramp was built over the old ramp at Austria Bastion. As part of the ramp construction, a triangular stair was built that led to a lower level where a connecting tunnel has now collapsed. (A sign at this stair indicates that it existed in 1742, and was used to access the lower level of the fort. This is incorrect. The stair must date from the 1770s, because two of its walls are from that period. Access to the lower level before 1776, was down along the ocean side.)

Santa Barbara Bastion achieved its present form during the 1770s. This work consisted of raising the level of the terreplein, extending the terreplein with embrasures to the southeast on the harbor side, using the walls of the earlier Granados Battery as a foundation, and constructing the casemates and embrasures along the north (ocean) side. If not constructed in the mid-seventeenth century, it is at this time that the dome over the tower room would have been built. Also, the sentry boxes, so much a symbol of the San Juan fortifications, were added as part of the 1770's construction campaign. The new type of sentry box had an ogee shaped roof and was corbelled out from the corners of bastion walls. They replaced an older style sentry box that had a semi-spherical roof and sat directly on a rounded portion of the bastion corner. This earlier type of sentry box is still seen at el Cañuelo, and at San Cristóbal's el Espigón.

By 1774, the north and east walls of Mercado Bastion were thickened inwardly, and the ramp that had communicated to the upper plaza was enclosed within the Carmen Battery wall, forming a gallery. The sloping line from the parapet of this earlier ramp can still be seen in the north wall supporting the gallery. On the west wall of Mercado Bastion is one embrasure. This embrasure is the only seventeenth-century embrasure remaining at el Morro. It survived only because the terreplein was not raised, and the wall here was not thickened. Also surviving on the opposite (south) side of el Morro, are the remains of the retaining wall that supported the earlier upper plaza. What is now only a projecting masonry mass, can be seen

on the 1742 plan as a four tier supporting structure at the western end of the Austria Bastion harbor wall.

In 1786, the present monumental entrance was added to the curtain wall on the north and the coat-of-arms of the Spanish king, Carlos III, placed in the pediment. (The existing coat-of-arms was reconstructed by the NPS.) The new entrance gate was connected to the glacis by an arched masonry bridge originally with a bascule, or drawbridge. This bascule was removed later in the nineteenth century, and an additional masonry arch was built to fill the gap.

By ca. 1790, the plan of el Morro was complete in the form we see today. The only modifications carried out in later years were installing more modern artillery emplacements and providing for better navigation aids. During the 1850s and 60s, muzzle-loading cannon emplacements, situated en barbette (above the parapet), were installed in several locations. These locations included the casemates and north terreplein of Santa Barbara Bastion, the Water Battery, and the north side of the Ochoa terreplein. The guns were mounted on a carriage that pivoted around a pintle placed near the parapet. The carriage had wheels that road on tracks laid in an arc. In the 1850s the tracks (3) were made of a dark stone with iron rails laid on top. Those on the Ochoa terreplein and at the Santa Barbara toe were from this period. The 1860s emplacements, those on the Santa Barbara terreplein, have tracks (2) of a lighter stone with no evidence of iron rails. These later emplacements may have used Rodman cannon or Parrott rifles purchased from the United States after the Civil War.

Although proposed in 1876 and again during the 1880s, it was not until the 1890s that breach-loading rifles were installed at el Morro. Two 15 cm Ordoñez rifles were placed on the Carmen terreplein in 1894, and in 1897, two 24 cm howitzers were installed on the Ochoa and Austria terrepleins, and three Ordoñez rifles on the terreplein of the high wall. With the exception of the howitzer emplacement on the Austria terreplein (removed in ca. 1940), all of these emplacements remain.

The nineteenth century saw the first Puerto Rican lighthouse added to el Morro. In 1845, a lighthouse was constructed on the terreplein of Austria Bastion. Built on a stone base, a tower of cast iron framing and plate was supplied by a New York foundry. It was this tower that was relocated to a new brick base on the Ochoa terreplein in 1876. An earlier signal tower had existed on Ochoa Bastion at the place to where the lighthouse was relocated. At the time of the relocation, a new Fresnel lens was installed in the lantern; it may be this same lens that remains, reused in the present lighthouse. During the May bombardment in 1898, the Spanish light tower was damaged. The Americans rebuilt it on its old base in 1899.

This first American tower developed cracks around its top, and in 1908, a second tower was built on the remaining 1876 brick base. It is this second tower that we see today.

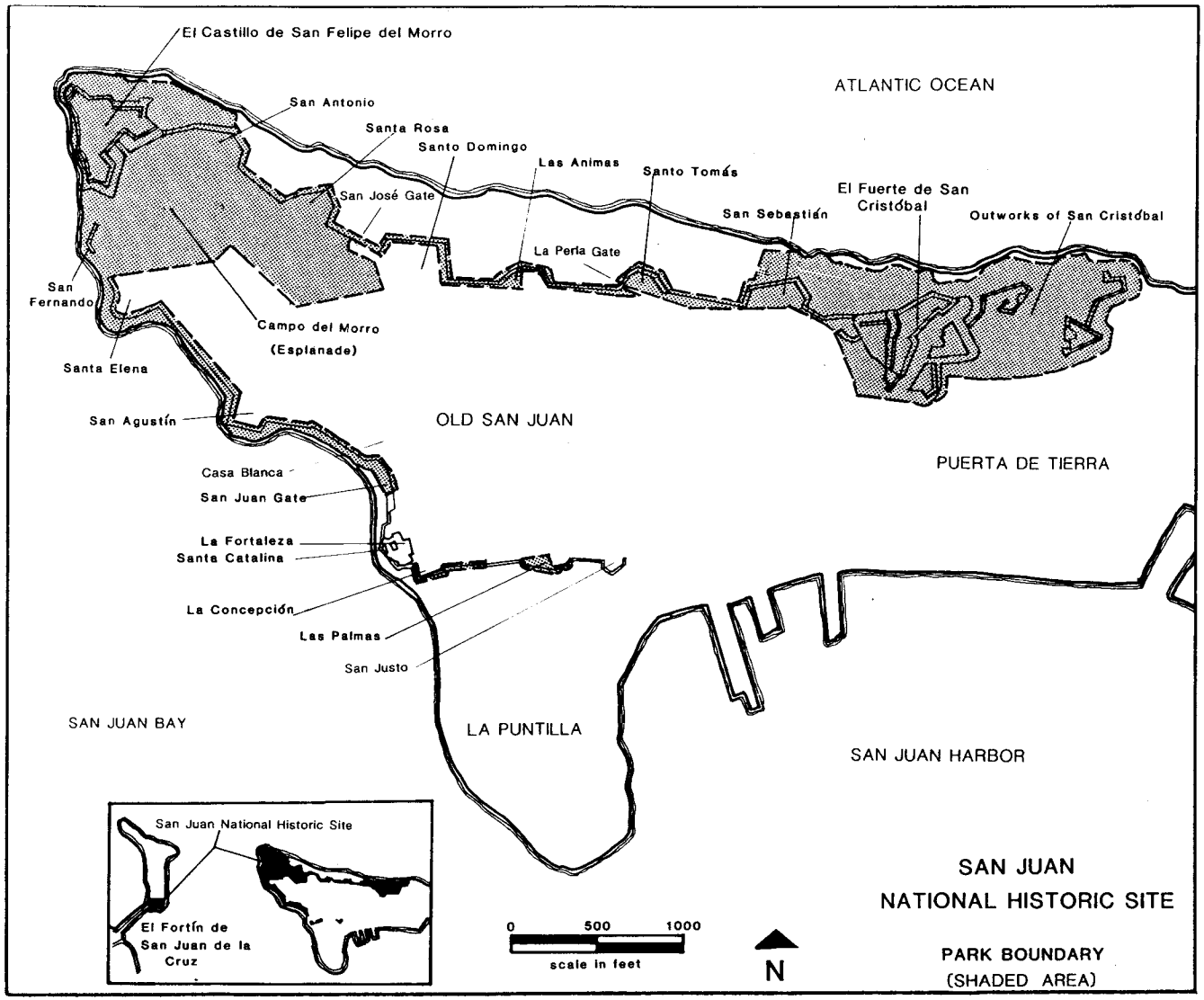
When the Spanish lighthouse was relocated to Ochoa Bastion, a new signal tower was built onto the old stone base remaining on the Austria terreplein. This tower was altered by the U.S. Army in 1902 by reducing its height for adapting to a modern use. In the 1938-40 efforts to restore el Morro, this tower was demolished.

With the twentieth century came a new ownership of el Morro. The U.S. Army brought new ways and new materials. Electricity was introduced to el Morro in 1901, and a new water supply system was built. The U.S. Army constructed new buildings on the grounds in front of the fort, and eventually a golf course was built with the ninth green located in el Morro's moat in front of Austria Bastion.

Damage to el Morro resulting from the American bombardment in 1898 was not repaired immediately. By 1925, concern for these repairs resulted in proposals for general repairs to the San Juan fortifications. In 1929, repairs to damage at el Morro were made after protests were raised by the local newspapers over the quality of work done in other areas of the fortifications. In 1939, the government began work intended to restore the historic appearance of el Morro in a manner sympathetic to the earlier construction. The embrasures on the north Santa Barbara terreplein, filled in by the Spanish in the 1860s, were restored. Additions or intrusions constructed by the U.S. Army, such as the water tower built on the Austria terreplein and an incinerator along the north wall, were demolished. In the process of this work, an eighteenth-century store house at the toe of Santa Barbara Bastion was demolished, as were the remains of the semaphore tower on the Austria terreplein. Restored, however, were the sentry boxes, the tops of which had been removed in the 1860s. (Of these sentry boxes, the only one to survive untouched at el Morro is on the harbor side of the Santa Barbara Bastion.)

World War II brought this preservation effort to an end, and the Army began a new focus; the development of a new harbor defense system. Modern shore batteries were constructed at points along the north coast. Towers for the newly developed radar were built at both San Cristóbal and el Morro. Concrete observation towers (called manholes) were built into the walls at both fortresses, and to facilitate communication, bunkers were constructed in their moats. Remnants or complete elements of most of these features remain comprising the last pieces in the 400 years of el Morro's evolution as a defensive bastion for the city of San Juan.

After World War II the function and use of el Morro changed dramatically. New modern weapons made fortresses such as el Morro obsolete. In 1961, el Morro was officially retired and became a part of the National Park Service site on San Juan. As a part of San Juan National Historic Site it receives many visitors who examine its physical remains in order to understand the long and glorious history of the fortifications. Today, the primary concern of the caretakers of el Morro (the NPS) is to preserve the extant elements of el Morro so that this history may be seen, interpreted, and understood.



Plan of the City Walls with features labelled and NPS boundaries shaded. (Drawing by K. Faust and annotated by R. Crisson, 1991.)

A SUMMARY OF THE CITY WALLS OF SAN JUAN

The masonry walls that partially surround old San Juan today are an important component of the San Juan fortifications and provided protection for the city from invaders beginning in the sixteenth century. The walls physically unite two other subjects of this historic structure report: el Castillo de San Felipe del Morro (el Morro) to the northwest, and el Fuerte de San Cristóbal (San Cristóbal) to the northeast. Also considered to be component structures of the San Juan fortifications are Casa Blanca and la Fortaleza that are mentioned in the section on the city walls but are not discussed as separate chapters in this report.* The walls are approximately three miles long, 2.7 miles of which are within the boundaries of the San Juan National Historic Site (SAJU NHS) that is managed by the United States Department of the Interior, National Park Service. The Commonwealth of Puerto Rico (the Commonwealth) owns approximately 0.3 miles of the walls, located on the south end of the city.** Construction of the walls began in 1586, but it was not until 1783 that they completely surrounded the city. Missing today are the east wall and a section of the south wall that were demolished in 1897 to make room for the growing city of San Juan. The walls that survive retain much of their eighteenth-century character despite alterations and repairs that have been made in the nineteenth and twentieth centuries.

Construction of a wall to protect the city began in ca. 1586 with the building of a rudimentary masonry wall at Santa Elena on the west (harbor) side of the city. Another wall at San Gabriel, later known as San Agustín, may also have been built about this time. These early walls were designed to enhance the natural defenses of the coastal cliffs to the south of the Castillo de san Felipe del Morro located on northwest side of the city (portions of Morro were begun as early as 1539). Other defensive structures associated with the city walls along the west coast were Casa Blanca (ca. 1520), la Fortaleza (ca. 1537-40), and la Puerta de San Juan or the San Juan Gate (ca. 1540). These coastal fortifications, including the city walls, were incorporated into the 1588 plan for the defense of San

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* Both Casa Blanca and la Fortaleza are under the jurisdiction of the Commonwealth.

** City wall features that are within the jurisdiction of the Commonwealth are la Fortaleza, Santa Catalina Bastion, the curtain wall between la Concepción and las Palmas Bastions, and San Justo Bastion and its west adjacent curtain wall. Also owned by the Commonwealth is Casa Blanca.

Juan executed by Juan de Tejeda and the Italian engineer Bautista Antonelli. The defenses held successfully against the English attack of Sir Francis Drake in 1595, but were useless against another Englishman, Sir George Clifford of Cumberland, who successfully invaded from the east (land) side in 1598.

The burning and ransacking of San Juan by the Dutch in 1625 finally convinced the Spanish that the city needed to be enclosed and its fortifications improved. As a result, extensive repairs, reconstructions, and new construction ensued in the years between 1630-50. Work included the rebuilding of the existing west city walls and the construction of new masonry walls on the south and east sides of the city. No wall was built on the north (ocean) side at this time because it was believed that adequate protection was provided by the rocky terrain and the cross fire from el Morro as well as by the new fort on the northeast side of the city - Fuerte de San Cristóbal.

The impending conflict between Spain and England in the mid-eighteenth century prompted another program of improvements to the fortifications of San Juan. Work was carried out in the years 1766-90 by Field Marshall Alexander O'Reilly, Chief Engineer Thomas O'Daly and Engineer Juan Francisco Mestre. The emphasis had changed by this time from the water front to the land front where a design known as "defense-by-depth" was employed. The plan also called for the rebuilding of the city walls to conform to the principles of bastioned fortifications. The west wall was completely redesigned and rebuilt as a series of straight curtain walls separated by bastions of triangular shapes. However, little work was done to the south wall except to raise its height additionally, because the wall was considered defensively obsolete. The east wall, on the other hand, was extensively reinforced as the third line of defense for the land front; it became, in effect, an extension of the newly-improved and enlarged outworks of San Cristóbal. Complete enclosure of the city was accomplished with the building of the north wall along the Atlantic Ocean. Construction began at el Morro and proceeded towards the east where it eventually joined with San Cristóbal. When completed, the walls on the west, south, east and north sides of the city enclosed a space of approximately 62 acres.

Five openings, or "gates," in the walls allowed access into the city. One was on the west harbor side, another on the south peninsula side, one on the east land side, and two on the north ocean side. These gates and the walls between them were guarded by sentries who were now able to take shelter in the newly-built sentry boxes. By 1790, the fortifications had reached the apex of their development, and the City of San Juan was known as one of the best fortified cities in the Caribbean. Its defensive strength was tested seven years later with a land

and sea attack led by England's Sir Ralph Abercromby. The invading force was successfully repelled.

Repairs and maintenance characterized the work that was done on the city walls throughout most of the nineteenth century. The City of San Juan prospered and grew, overspilling its walls of protective masonry. In 1814, the municipal cemetery was established outside the north wall near el Morro. Shortly thereafter, the area outside the north wall near San Cristóbal, known today as la Perla, began to be populated. Finally, in 1897, most of the east city wall south of San Cristóbal and a portion of the south wall was demolished to allow the city to expand to the south east. A few modifications were also made about this time to what was left of the city walls to prepare San Juan for the impending war with America. Platforms of concrete were poured and modern guns were emplaced on top of some of the walls. Despite these precautions, however, San Juan did not withstand the assault of the American forces and Puerto Rico became a possession of the United States on October 14, 1898.

Jurisdiction of the city walls was under the United States Department of the Army for the years 1898 through 1961. While the Army planned to repair the walls in the early years of the twentieth century, a lack of funding resulted in neglect and deferred maintenance. Their condition had so deteriorated by 1912 that a population of rats living in the walls was cited as a contributing factor in an epidemic of bubonic plague that swept the city.

The first significant work was not done until 1924-25 when a section of the west wall was repaired. Other work followed in the 1930s and the 1940s when other portions of the north and west walls were rebuilt, nine sentry boxes were reconstructed using concrete blocks, storm sewers were installed, and general cleaning, patching and reinforcing repairs were made. The quality of the repairs met with some criticism from preservation-minded people who contended that the work was being done in a manner unsympathetic to the historic structures. Work was brought to a halt shortly thereafter, not by the critics, but by the funding shortages of World War II.

Following the war, in 1956, a more sympathetic approach was taken in the restoration of the west-facing San Juan Gate, carried out under the direction of the National Park Service. Five years later, in 1961, the United States Department of the Army transferred the jurisdiction of most of the city walls to the United States Department of the Interior/National Park Service.

The city walls that survive today are composed of three sections: the west wall, the south wall, and the north wall.* These will be described beginning on the south side of el Morro and moving in a counterclockwise direction. (See plan of city walls on page 39.)

The west wall faces San Juan Bay and includes the earliest sections of masonry that date to the sixteenth century, although the bulk of the masonry dates to the eighteenth century. It is approximately 3,250 feet long and varies in height from 20 to 50 feet. Major features are four bastions, two curtain walls, 55 embrasures, five sentry boxes and one gate. The bastions are named San Fernando, Santa Elena, San Agustín, and Santa Catalina.** The curtain walls derive their names from the adjacent north bastions, hence the names Santa Elena curtain wall and San Agustín curtain wall. The embrasures are located in both the bastions and in the curtain walls. Of the five sentry boxes, two are of original eighteenth-century construction and three were reconstructed in the twentieth century. The city gate, the San Juan Gate, was the primary entrance into the city from the harbor; it was restored in 1956. Also an important component of the west wall is la Fortaleza, now used as the mansion of the Governor of Puerto Rico.***

The south wall cuts across the peninsula of land that is known as la Puntilla. It is about 1,500 feet long and varies in height from 20 to 60 feet. The south wall is mostly of seventeenth- century construction. Major features are three bastions, two curtain walls, two embrasures and one sentry box. The bastions are named la Concepción, las Palmas and San Justo.**** Two curtain walls separate the three bastions; half of las Palmas' bastions and three-fourths of the curtain walls are owned by the Commonwealth. The solitary sentry box at las Palmas Bastion dates to the eighteenth century. Missing today is the east end of the south wall and its gate (la Puerta de San Justo); both were demolished in 1897. The sentry box at

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*The National Park Service labels the west wall as "South Wall #1" and the south wall as "South Wall #2" in its list of classified structures.

**Santa Catalina is owned by the Commonwealth of Puerto Rico.

*** La Forteleza and its adjacent city wall is owned by the Commonwealth of Puerto Rico.

**** San Justo Bastion is owned by the Commonwealth of Puerto Rico, and has an extant eighteenth-century sentry box.

la Concepción has not been reconstructed as so many others have been during the twentieth century.

South of San Cristóbal, nothing remains of the city's east wall and gate (la Puerta de Santiago) that once protected the land side of the city. As with the east end of the south wall and la Puerta de San Justo, they were demolished in 1897.

The north wall faces the Atlantic Ocean and connects el Morro and San Cristóbal. It is approximately 11,100 feet long, 15 to 30 feet high, 50 feet wide at the base and 24 feet wide at the top. The material of this wall dates primarily from its original construction in 1776-83. Its major features are six bastions, six curtain walls, 78 embrasures eight sentry boxes, and two gates. The bastions are named, from east to west, as follows: San Sebastían, Santo Tomás, las Animas, Santo Domingo, Santa Rosa, and San Antonio. Of the eight sentry boxes, three are of original eighteenth-century construction and five are twentieth-century reconstructions. The two gates also date to the eighteenth century and are named la Puerta de la Perla on the east end of the wall and la Puerta de San Jose on the west end of the wall. Two developments dating from the nineteenth century exist outside of the north wall today. These are; the neighborhood of la Perla and the municipal cemetery near el Morro.

In general, the condition of the city walls is generally poor. They suffer from surface cracking, differential weathering, biological growth, and staining. Most of these problems stem from water infiltration and a lack of regular maintenance repairs. A program of regular inspection and repairs is necessary to halt their deterioration.

Despite their condition, the walls retain their integrity as impressive reminders of San Juan as a fortified city. They are of great significance to, and an important component of, the overall fortifications system of San Juan.

A SUMMARY OF THE CULTURAL LANDSCAPE OF EL CASTILLO DE SAN FELIPE EL MORRO

The Cultural Landscape Report (CLR) was prepared as a result of the Puerto Rico State Historic Preservation Office (PRSHPO) coordinating the "Inner City Rehabilitation Plan for the San Juan, Puerto Rico Historic Zone."* A cultural landscape is defined by the NPS as a geographic area (including cultural and natural resources and the wildlife or domestic animals therein) that has been influenced by or reflects human activity or was the background for events or a person significant in human history. This CLR examines just the area facing toward land in front of el Castillo de San Felipe del Morro. This area was open during most of its history as it was the original glacis; the sloped land in front of a fortification kept clear of all obstacles so that it could be swept by the fire of the defender. Although some plans call the area el Campo del Morro, (the Esplanade of el Morro), early twentieth-century documents referred to it as "the parade ground." Today, it is usually called simply the "Esplanade," and so it shall be referred to throughout the CLR.

The CLR for the Esplanade identifies, evaluates, and determines the appropriate recommendations for the development and management of the Esplanade based on an analysis of the historical evolution, significance, and integrity of the landscape. The study also identifies primary views that have been important throughout the history of the site and that merit preservation. The CLR identifies areas that can accommodate appropriate recreational activities and locations where vegetation may be planted that will not disrupt the views of primary historic importance.

The Esplanade of el Morro contains 23 acres and is found at the rocky promontory lying at the extreme northwest point of the islet of San Juan. It began as a fortified site ca. 1540, when it was referred to by the Spanish as el Morro, meaning the bluff or headland. (The geographic advantages of this site may have been apparent even earlier to the native Indian population.) The site soon became known as el Castillo de San Felipe del Morro.

Both el Morro and its Esplanade are integral features of the cultural, historical, and architectural ensemble of the San Juan fortifications. The Esplanade and el Morro are often

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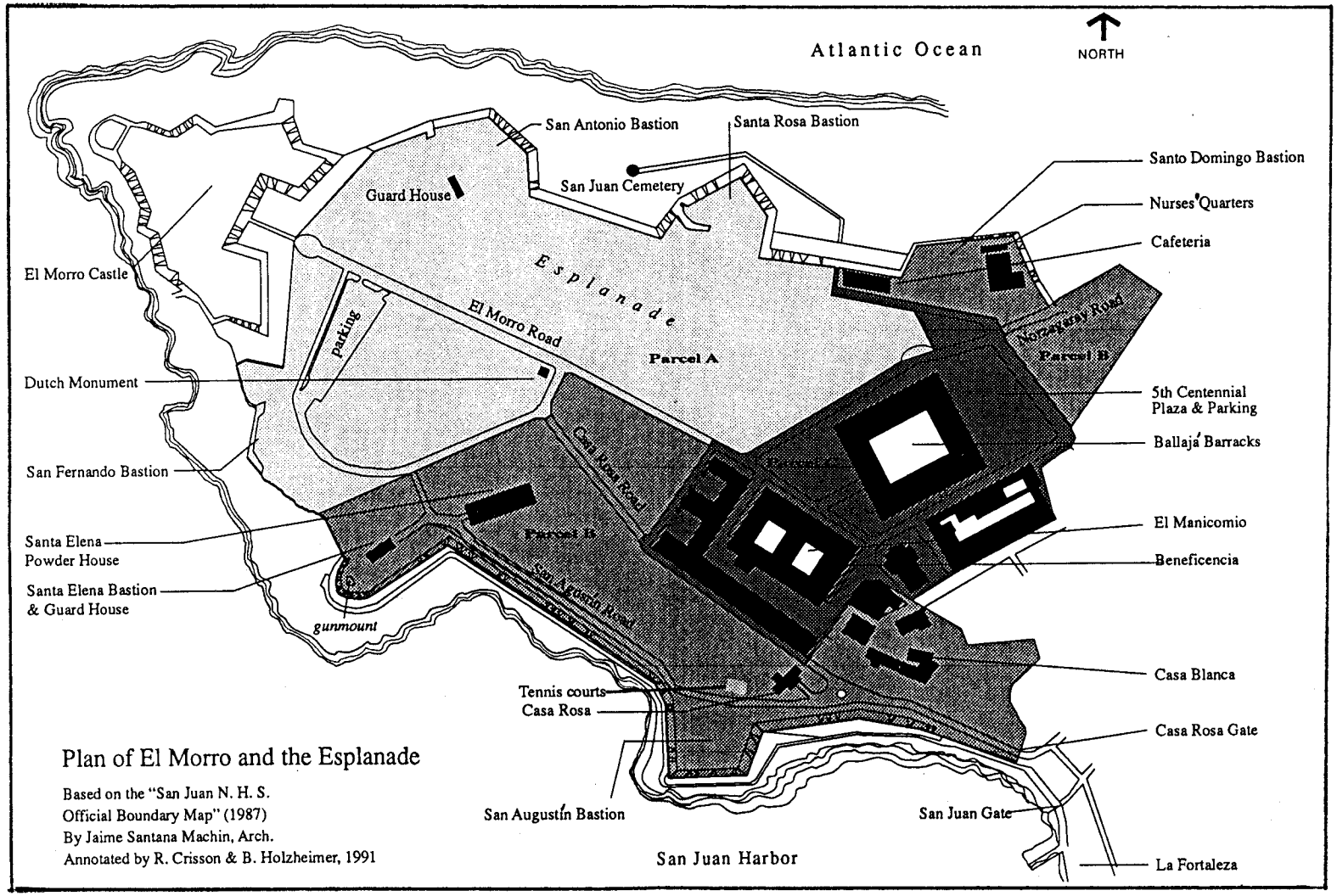
* This project is referenced in the Memorandum of Agreement (MOA), No. MA-5000-0-9001, signed August 1, 1990.



Study area. This site plan indicates the study area for this report and Parcels A, B, and C. The study area is shown within the dashed line and the parcels are differentiated by varying textures.

discussed as a whole because they are components of a military site performing as one defensive unit.

The Esplanade has been expanded for this report to include all or part of three parcels that are administered by the NPS and the Commonwealth. (See plan included on page 46.) Parcel A is administered by the NPS, while Parcel B and C are managed by the Commonwealth. A distinction was made to discuss more fully those features within Parcel A, and to differentiate them from features outside of the Esplanade in Parcels B and Parcel C. The study area was defined on the northwest by the walls and dry moat of el Morro, on the west by an embankment and the walls of San Fernando; followed by the parapet walls of Santa Elena; and ending on the south and west by the parapet walls of San Agustín--a portion of which are today called Casa Rosa and the Casa Rosa wall. Parcel B terminates at the extreme south by the Casa Rosa Gate. The east boundary of the Esplanade, on Parcel C, is defined west to east by three masonry structures: el Manicomio, or the Insane Asylum (now the School of Plastic Arts); el Asilo de Beneficencia, or the Welfare Asylum; and el Cuartel de Ballajá, or Ballajá Barracks.

The eastern edge of the Esplanade is defined by various elements that are also on Parcel B and C, administered by the Commonwealth: the Fifth Centennial Plaza and Parking Garage; Santo Domingo bastion, containing the Neurological Institute (often referred to by its former name, the Nurses' Quarters); and terminating with another large structure (known by its former name as the Cafeteria). The Esplanade is enclosed on the north by the north city wall, defined east to west by the two bastions of Santa Rosa and San Antonio.

The Esplanade evolved over time, but its function as an open glacis and as a parade or training ground remained unchanged into this century. The form and character of the Esplanade remained largely unchanged until ca. 1930. While the defensive military significance of the site decreased in the twentieth century, more structured recreational uses of the fortifications began to appear. The height of recreational use within the Esplanade occurred after 1930 when all recreational facilities installed by the US Army were in place, such as the golf course in front of el Morro.

The period of primary significance for the site is from ca. 1540-1898. Although the fortifications of San Juan were viewed in the General Management Plan (GMP) as an historic district that evolved over time, the GMP also emphasizes that the significant historic period is the period of Spanish occupation, ca. 1540-1898. The Esplanade is described as a highly significant part of the historic scene during this period. The GMP recommended that a long-term preservation

management philosophy be instituted to prevent the arbitrary removal, alteration, or destruction of the historic fabric.

Because SAJU NHS is located within the congested urban center of Old San Juan, open space is considered to be important. In accordance with the GMP, recreational activities were recommended to remain as long as they were compatible with the primary purpose of cultural resource preservation. The goal of the overall theme presentation at SAJU NHS is to understand the nearly 500 years of history represented by the fortifications of San Juan.

All of the land within the boundary of SAJU NHS is managed as a historic zone. Zones were identified based on the authorizing legislation, NPS policies, the nature of the site's resources, the desired visitor experience, and established uses. The unstructured recreation subzone includes the Esplanade. This subzone was designed to preserve historic structures and settings and to allow casual outdoor recreation activities.

The CLR traces the evolution of the landscape from ca. 1540 to the present. Character-defining site elements were found to be: circulation, structures, land form, vegetation, small-scale features, utilities, and views. Pertinent site elements serve as broad categories under which the documentary data was analyzed and recorded. The entire site history was reviewed to determine that two distinctly different types of landscape character existed, generally corresponding to the periods of Spanish and U.S. occupation. These two periods have been classified as Period I, ca. 1540-1898, and Period II, ca. 1898-1961.

An open and undeveloped landscape character existed during Period I; vegetation and structures were kept to a minimum; and circulation and land forms remained relatively constant.

Period II begins with the U.S. occupation commencing late in 1898 as a result of the Spanish-American War. The landscape character of the Esplanade began changing almost immediately. The former military function of the Esplanade as an open landscape designed for defensive and ceremonial purposes, changed to that of a residential and recreational support facility. The appearance of the Esplanade that had existed for some 350 years was replaced by one that would last approximately 60 years. Between 1898 and ca. 1930, Officers' Quarters were built near the fort. Palm trees were planted near the buildings, and a number of small-scale features were installed. From ca. 1930 onward, the U.S. Army developed the Esplanade even more intensively. New roads and structures were constructed, and numerous trees were planted along the roads. Although the military era of el Morro ended in 1958 (when the

last U.S. Army troops left the fort), it was not until 1961 that the land contained within the former Fort Brooke Military Reservation (including the Esplanade) was conveyed to the U.S. Department of the Interior. 1961 thus marks the end of Period II.

Today, the NPS goal for the Esplanade is neither to strictly preserve nor to recreate an already-disrupted historic scene, but to maintain the individual landscape components that form the historic character of the area and to provide for compatible uses. The recommended plan within the CLR, to rehabilitate the landscape to Period I, provides the greatest opportunity to meet this goal, in terms of both preservation and site interpretation.

The main advantage of the recommended plan is that it returns the Esplanade to an appearance characteristic of the chosen period of significance. The plan promotes the primary historic views associated with the Esplanade. It also allows the significant historic period, the Spanish era, to be the primary focus of interpretation.

Two other options for the site (in addition to rehabilitating to Period I appearance) were considered. These options were to rehabilitate the site to its Period II appearance or to take no action at all. The Period II rehabilitation option was rejected because its primary focus of interpretation would diminish the importance of the Spanish period of occupation. The primary historic views would be obstructed by vegetation. Most of the major structures on the Esplanade associated with Period II are gone and probably would not be reconstructed due to policy and budget constraints. Thus, a Period II rehabilitation would not provide a suitable visitor interpretive experience.

No-action was also rejected because it, likewise, does not focus on the Spanish period of occupation as the primary period of interpretation. This no-action option would be the least costly to implement, but it would not enhance the interpretation of the site. Nor would it clarify the issues of management, development, and interpretation of the Esplanade. This option was considered to be inconsistent with NPS preservation policies.

As a summary to the recommended plan contained in the CLR, are the general guidelines for the proposed landscape plan. The two components of the landscape plan will be a Vegetation Management Plan and a Landscape Design. The Vegetation Management Plan will identify existing materials, determine their condition, recommend their treatment, identify historic structures and walls, and ensure their protection. The Landscape Design (intended to be executed as a subsequent

phase) should be consistent with the CLR recommendations, and will focus primarily on Parcel B. The goals of the landscape design are to provide a pedestrian-oriented and handicapped-accessible facility; provide non-intrusive improvements compatible with the existing site character; develop a planting design that includes native material suitable to the environment, but requiring low maintenance; ensure the protection of historic structures and walls; and develop a routine maintenance program for existing and new plant materials in accordance with existing NPS maintenance management system programs.

II. CONDITIONS SURVEY OF THE SAN JUAN FORTIFICATIONS

INTRODUCTION

This report documents the conditions of the fortifications of the San Juan NHS and describes the primary deterioration mechanisms active on-site.[1] The fortifications are constructed primarily of masonry materials and therefore, deterioration of masonry materials will be given the greatest emphasis in this discussion.

The site research for this report was carried out in conjunction with the materials study during the summer of 1988 and the winter and summer of 1989.[2] Additional information on conditions was gathered from reports of previous conditions studies and contemporary literature concerning the deterioration of buildings and building materials. Laboratory analysis of materials was also carried out.

At first glance, the fortifications appear to be in overall good condition with their massive configuration suggesting immortality. Upon closer examination, this appearance is deceptive. Surfaces are badly eroded with conditions becoming ever more severe. There is a desperate need for the preservation of material that remains extant. Before such work can commence however, it is necessary to identify problems and understand the phenomena that have led to these problems. This information can then be used to establish recommended treatments.

This report presents an overall condition assessment of the fortifications, followed by conditions assessments specific to features and materials; a general route will be travelled that begins on the exterior face of the fortified walls and moves inward into the walls themselves and then to interior spaces. Masonry materials will be discussed first followed by all other materials. The worst condition evident will be considered "poor;" materials or features that are now completely gone will not be discussed.

The U.S. Army carried out the first restoration efforts in the fortifications. These efforts, continued by the NPS, have removed or otherwise altered historic and non-historic fabric. The general condition of the fortifications, and the specific condition of particular elements, has been affected by these restorations. Current conditions will be discussed only in terms of extant materials and their degradation. The philosophical appropriateness of such efforts will not be discussed in this report.

HISTORY OF CONDITIONS SURVEYS

Conditions surveys have been carried out on a regular basis since the initial construction of the fortifications. Spanish documents describe both good and bad conditions, with the latter predominating. New work often followed a poor conditions assessment; if money was to be obtained from Spain, it was necessary to fully describe the plight of the fortifications. It is not surprising that poor conditions are documented more often than good conditions. Documents from the U.S. Army describe material conditions as well.[3] The NPS has made several studies during their tenure. Until recently, they have been primarily concerned with individual structures.

Historical condition surveys have not been as helpful to the preparation of this report as they have been to the developmental studies of San Cristóbal, el Morro, and the city walls. Nevertheless, they clearly indicate that poor quality materials and construction, in conjunction with the deleterious effects of the environment, have led to deterioration.

Since 1986, several conditions surveys and assessments have been prepared for the fortifications by the Center for Preservation Research (CPR; Columbia University, New York, New York) and the Historic Preservation Center (HPC; National Park Service, Boston and New York offices). These were extremely useful in guiding the production of this report, both for obtaining a better understanding of conditions and determining the most suitable approach for their discussion. This report restates most of the observed deterioration recorded in these surveys, and discusses reasons for deterioration.

Both CPR and HPC documented conditions for each of the San Cristóbal units at the end of each unit chapter. These were written in conjunction with morphological histories and are generally short, describing both pathology and physical configurations. They serve to provide a good introduction to conditions at the site.

CPR carried out a much more detailed conditions survey of the city walls and el Morro, expressing their data graphically in a series of drawings of all embrasures and photographic reproductions of el Morro. This study (available at the HPC, Boston, MA) also provides a good overview of conditions.

CONDITIONS AND FORCES OF DETERIORATION

The types of deteriorated conditions observed in the fortifications are the result of the materials and building systems used, the coastal tropical climate, as well as the human impact. Many problems are moisture related. Because deterioration of building materials and systems has been thoroughly discussed in literature on the subject, the mechanisms of general deterioration will not be discussed here.[4]

The climate of Puerto Rico is characterized by the high temperature and humidity of coastal tropical regions. Days are primarily sunny. Rain storms are frequent events, generally of short duration but with quite heavy downpours. Hurricanes and violent storms are prevalent in the summer months and can be especially damaging with high winds and rain. Earthquakes are not as frequent as hurricanes but do occur on a periodic basis. Tropical climates promote the rapid growth of vegetation.

The ambient air of San Juan is relatively clean for an urban setting. The trade winds blow from the northeast, and though it is possible that airborne pollutants are brought over from Europe, it is not known to what extent the air quality of San Juan is affected. Exhaust fumes from automobiles are present, but are largely blown inland.[5]

Construction materials of San Juan are discussed in Volume III, **MATERIALS**. In general, masonry materials (stone, brick, mortar, stucco) are porous and especially prone to harsh weathering and other environmental forms of deterioration.[6] Native hardwoods, on the other hand, are extremely durable and not easily affected by decay producing organisms. Both iron and bronze were used in San Juan; the former is far more prone to deterioration when left without an applied finish.

Exposure and Weathering

Exposure plays a key role in the susceptibility of materials to deterioration. Windward surfaces receive harsher weathering than leeward. Protruding elements receive harsher weathering than receding. Horizontal surfaces are especially affected by hard pelting rains. In most cases, surfaces especially vulnerable to weathering are in worse condition than those not.

The weathering of materials will occur in any environment. The forces affecting materials in San Juan include the erosive action of the sea, salt water and fog, wind-borne abrasives,

and varying temperatures and humidities. These act in synergy to erode surfaces and impact sub-surface conditions.

Natural sand-blasting is part of the weathering process. Fine grit or dust can be wind-borne and if the wind is especially strong, the resulting impact has an abrasive effect on materials. Initial deterioration may not be visible with the naked eye, but with time, smooth surfaces become roughened and a loss of material becomes evident.

Two sets of photographs serve to illustrate the rate of deterioration of stuccoed surfaces. The first series is of the south salient angle of Austria Bastion, dating to 1938, 1961, and 1989 (figs. 1, 2, and 3). (The top of the sentry box was reconstructed in the late 1930s.) The second set is a sentry box on Santa Barbara Battery, dating to ca. 1898, 1961, and 1989 (figs. 4, 5, 6). The finial was reconstructed in the late 1930s and the enlarged window opening most likely filled in at this time as well. It is evident that there has been a tremendous loss of original surface over the years. The smooth white stuccoed surface of the nineteenth century has become rough with only small areas of the original surface remaining.

Weathering will erode surfaces and materials at different rates; softer (or less cohesive) and more porous materials are generally eroded faster than harder (or more cohesive), denser materials. Differential erosion is apparent throughout the fortifications. One example is the former oven on the Water Battery of el Morro (fig. 7). The mortar, being less cohesive than its associated brick and stone, has eroded at a faster rate and is now recessed in the wall. It is possible that these joints were never flush with the masonry units and were originally slightly recessed, in which case, weathering has simply augmented the condition. Weathering has also affected masonry units, but to a lesser extent. Both brick and stone have acquired the rounded edges characteristic of erosion.

The wall of the curved ramp leading to the main gate of San Cristóbal also displays differential erosion (fig. 8). Cement patching surrounding the brick arch is barely eroded while the softer brick have almost eroded completely away. (The detrimental effects of cement will be discussed later in the text.) The infill within the arch suffers from a loss of stucco and mortar while the masonry units remain intact.

One of the most dramatic examples of differential erosion is found at the lighthouse on el Morro (fig. 9). The lighthouse was constructed in two different years; the upper (and newer) portion has deteriorated to a much greater degree than the lower. "Honey combing" is the phenomenon where brick become severely eroded and the mortar joints remain intact. (This will be discussed to a greater extent later in the text.)

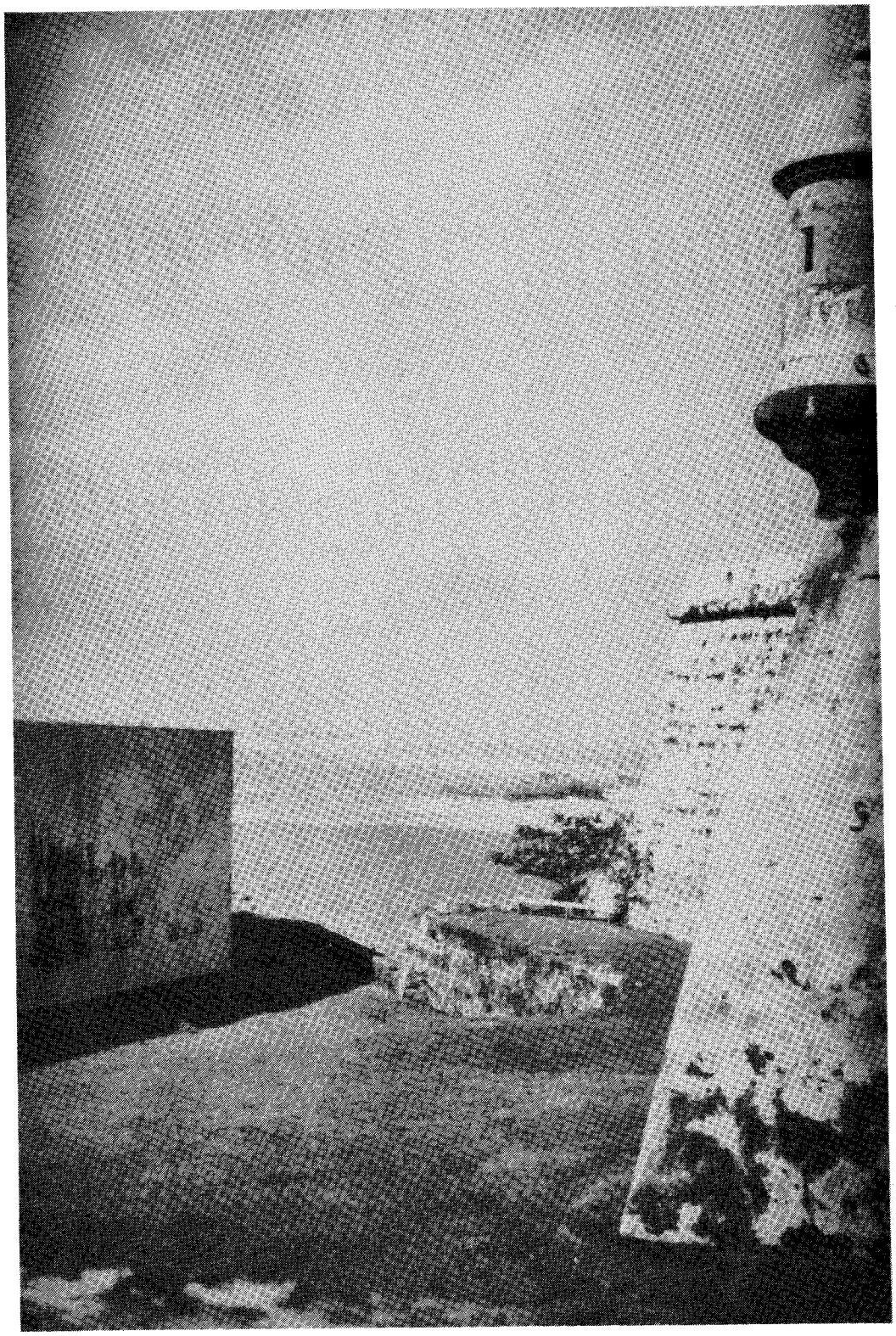


Figure 1. Austria Bastion, south salient angle. (Photo by T.T. Waterman, 1938. HABS, PR 7-SAJU 6-8, PR 48, 16616.)

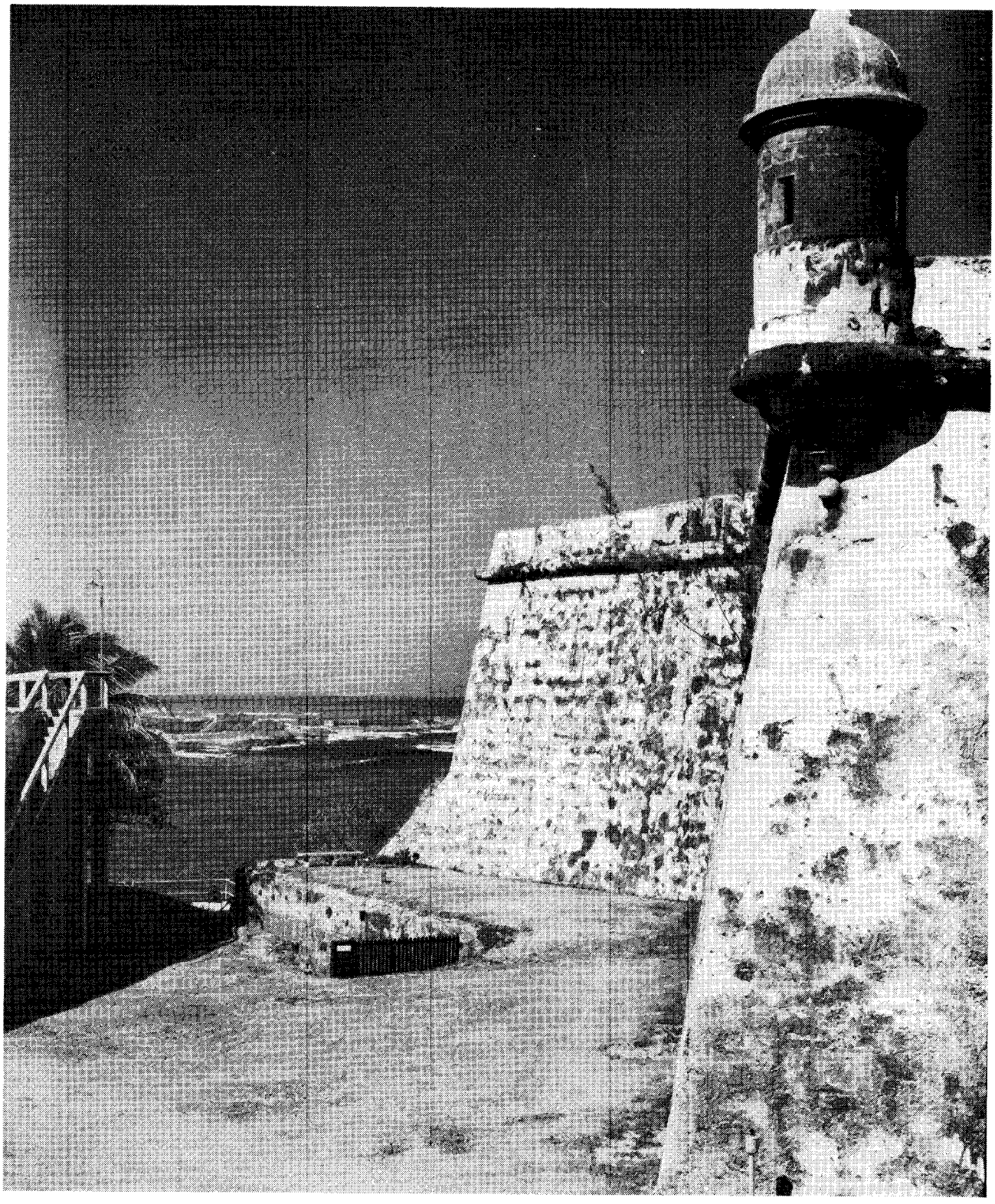


Figure 2. Austria Bastion, south salient angle. (Photo by J. Boucher, 1961. HABS, PR 48-11, 7-SAJU, 6-11, 16616.)

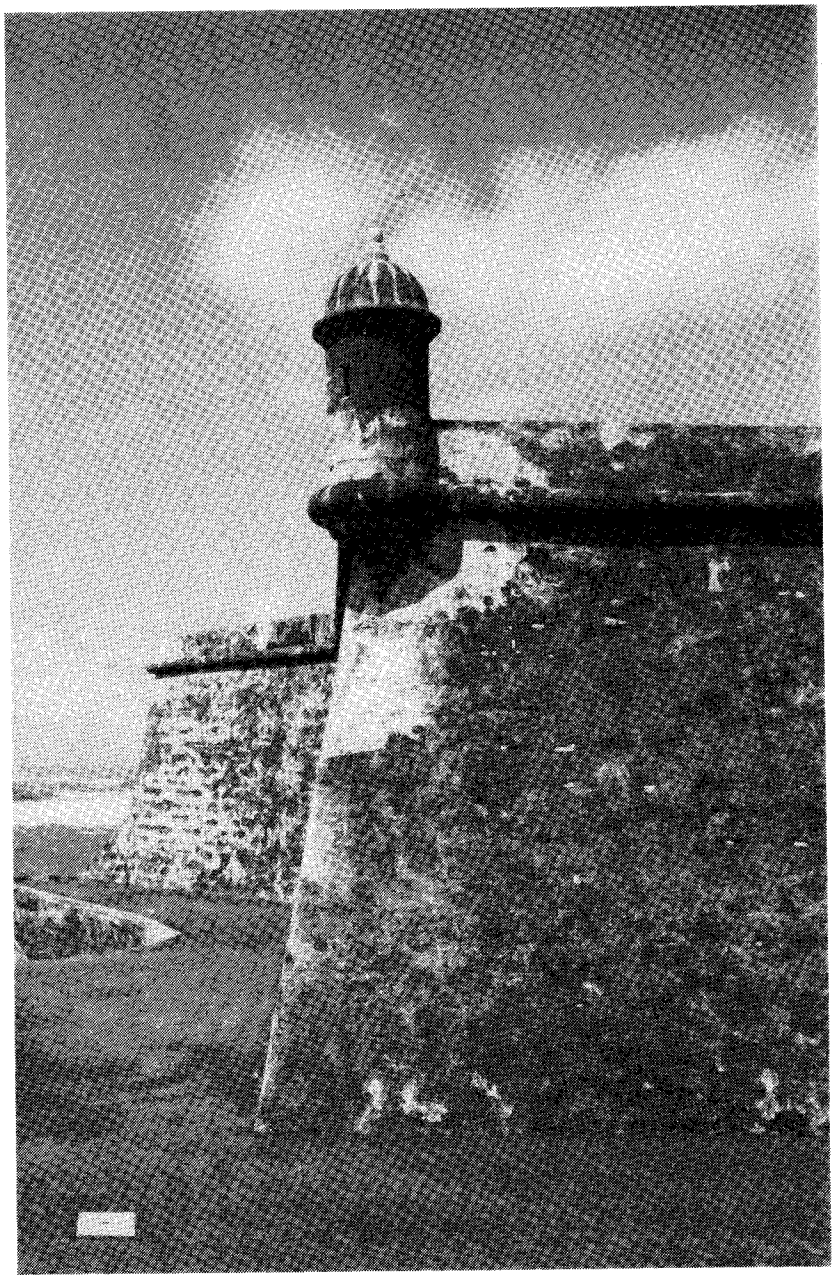


Figure 3. Austria Bastion, south salient angle. (Photo by J. Jacob, 1989.)

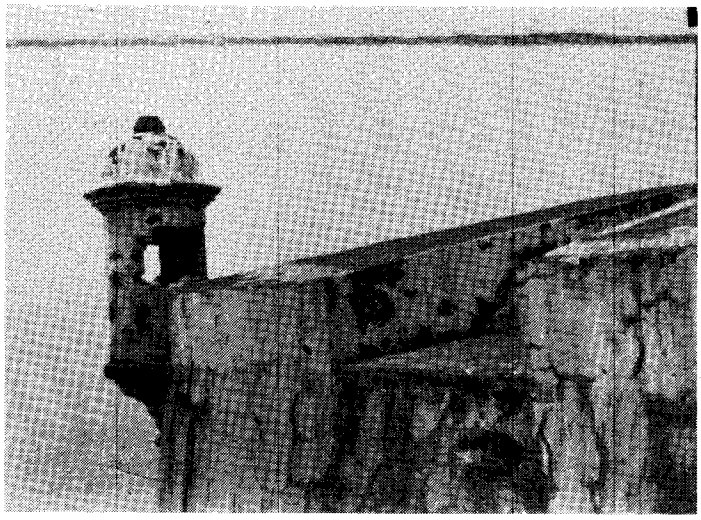


Figure 4. Santa Barbara Battery, sentry box. (Photographer unknown, ca. 1898. San Juan NHS Archives.)

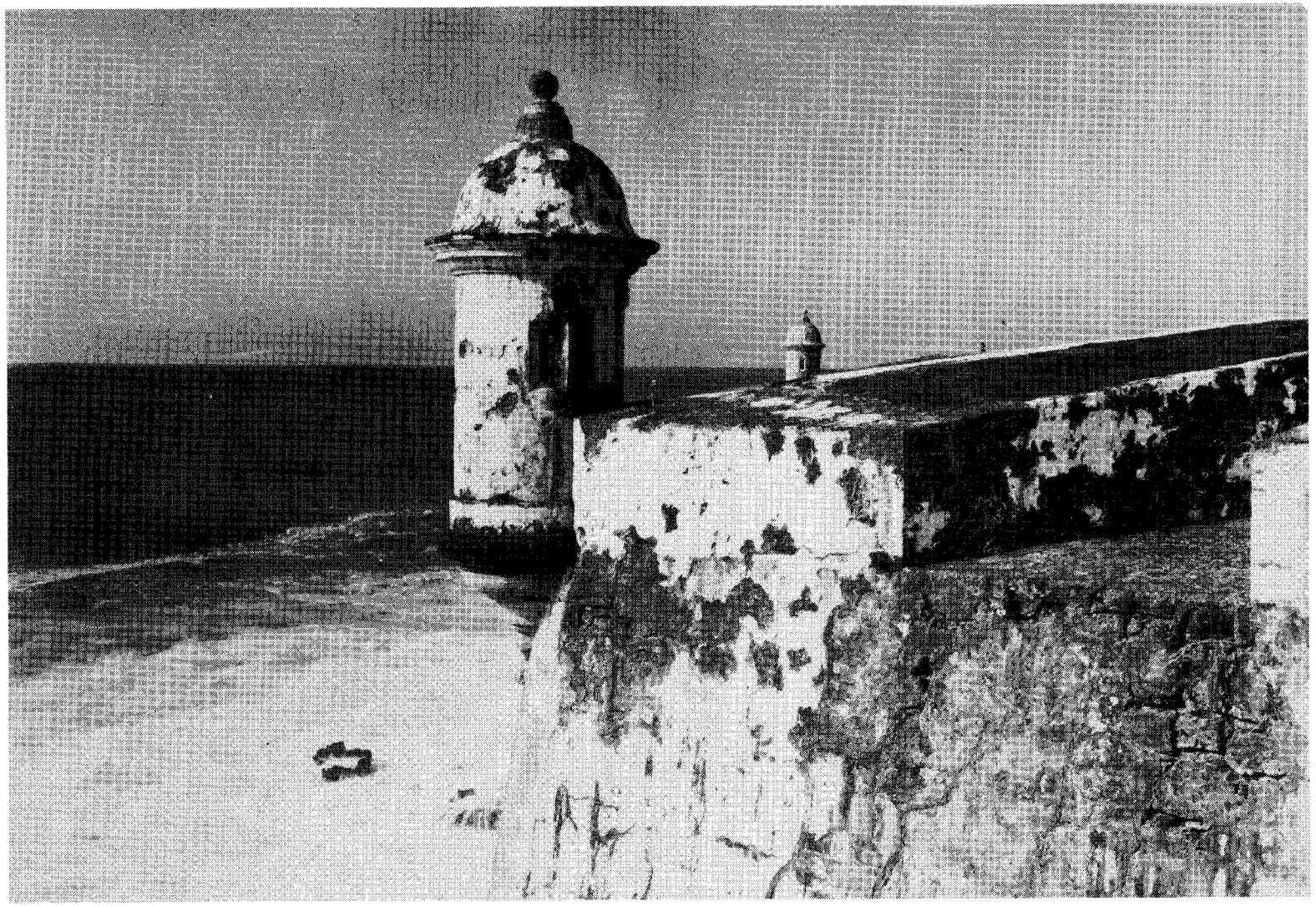


Figure 5. Santa Barbara Battery, sentry box. (Photo by J. Boucher, 1961. HABS, PR-48-16, 16616.)

Figure 6. Santa Barbara Battery, sentry box. (Photo by J. Jacob, 1989.)

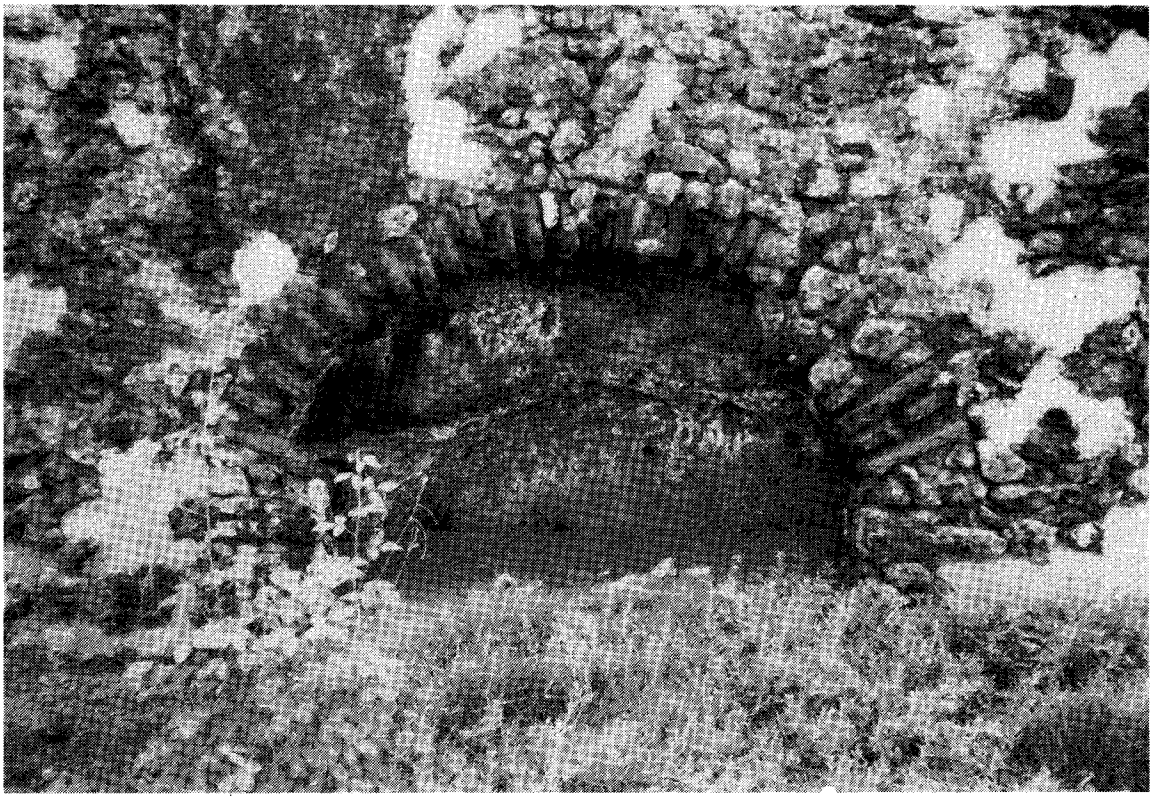


Figure 7. Water battery, former oven. (Photo by W. Sedovic, 1988.)

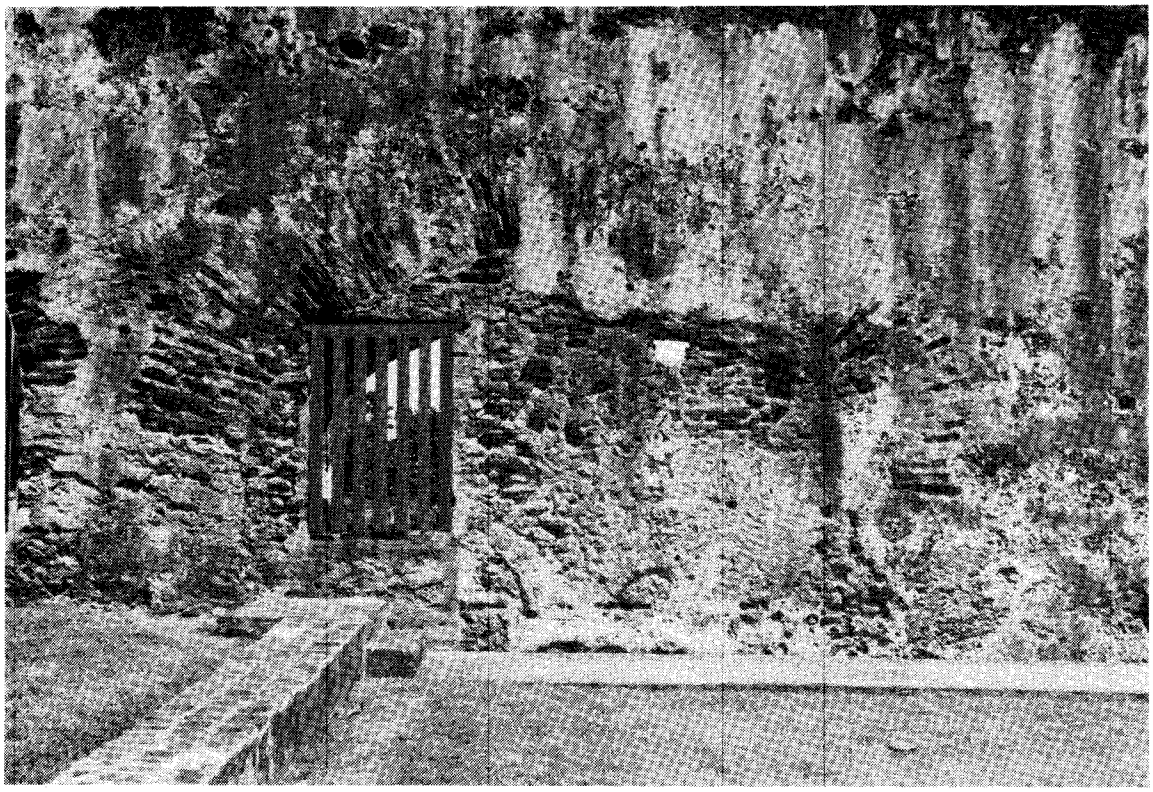


Figure 8. San Cristóbal, north wall of ramp leading to Main Gate. (Photo by J. Berkowitz, 1986.)

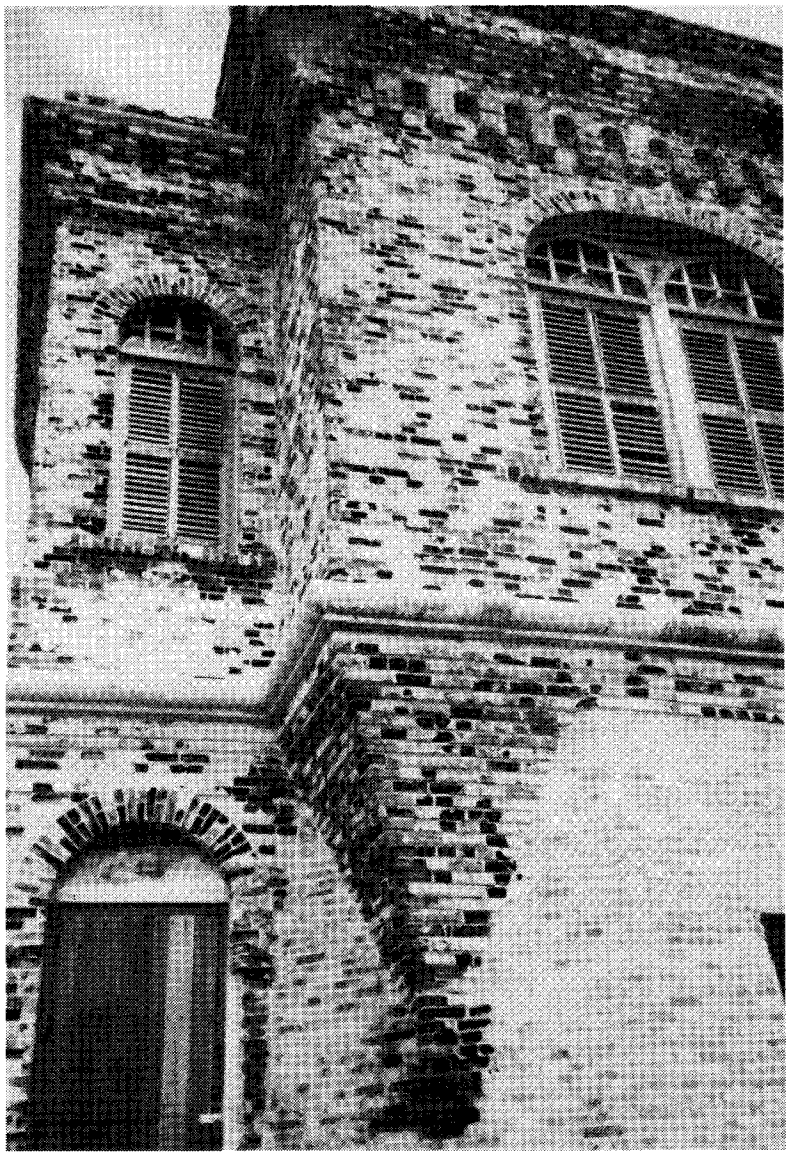


Figure 9. El Morro, lighthouse. (Photo by W. Sedovic, 1988.)

A noticeable aspect of erosion is the amount of material displaced by rain. After every rainstorm, loose particles of stucco and mortar are washed free of their structures and lay strewn about on the plaza levels of el Morro and San Cristóbal. Wind storms most likely have the same effect.

The fortifications are situated directly on the coast. Some elements sit adjacent to the water (el Espigón and the Water Battery of el Morro), others sit on rocky bluffs above (San Cristóbal and the upper bastions of el Morro). During storms, waves crash against the lowest elements and salt spray covers the walls; the ensuing erosive action is significant.

Water and Water Vapor

Water has an enormously deleterious effect on building materials. The fortifications were constructed to facilitate rain water run-off, both guiding it to cisterns and preventing infiltration into building materials. A smooth hard surface of stucco and an extensive drainage system were primary features of this system.

If the fortifications had been kept in their original condition with smooth surfaces and working drains, many of the problems visible today would not be present. However, there has been a general decline in up-keep from the mid-nineteenth century and once deterioration began, it became increasingly worse. The ability of the fortifications to shed water effectively has long since been lost. Parts of the drainage system are no longer functional and most exterior wall surfaces have eroded to a great extent. The problems associated with wetness are far-reaching and growing worse with time.

Water and water vapor enter masonry materials through their pores with pore structure and size determining the quantity and rate of absorption as well as evaporation. The movement of water vapor within a material is dependent upon ambient temperature and humidity; movement is always towards areas of lower humidity and lower temperature.

A high moisture content can cause slumping of earthen materials within the interstices of walls. High moisture levels and slumping can set up internal stress that may have severe deleterious effects on the structural stability of walls. Moisture content within walls was not measured for this report.

In a marine environment, splashing waves and fog introduce salt ions into masonry materials. When the water component evaporates, the ions bond to form salt crystals. The expansive force of crystallization causes the displacement of minute

particles of the surrounding material that are then washed away with rain or blown away by wind. Efflorescence denotes the visible salt crystals on a masonry surface (sometimes appearing as a white haze). Though many of these crystals are blown or washed away, many remain on the surface or within pores close to the surface. With rain or condensation, these are put back into solution and will reenter the substrate. The process continues with crystallization occurring at different points within the surface zone, augmenting deterioration. Smooth surfaces affected by efflorescence eventually become pitted and rough. The resulting increased surface area increases the rate of water absorption, and thus increases the area for salt crystallization and material loss. Salt crystallization and natural abrasion often act in unison to erode surfaces.

Water will slowly affect soluble substances. Sometimes crystalline deposits are visible on interiors or the undersides of a mass where water has percolated through. Stalactites and stalagmites are found within some vaults at both San Cristóbal and el Morro. These are presumed to be calcium carbonate (samples were not analyzed for this report) originating from the mortar and possibly the stone of the mass above. It is not known how this loss of material is affecting the structural integrity of these areas.

Vegetation

Vegetation, on both the micro and macro levels, grows rapidly in Puerto Rico. Although conditions were considerably worse during the U.S. Army tenure and early years of the NPS, conditions today are bad. Prior to the cleaning of the fortifications in 1989, many of the walls were black in color, or marked by large black patches. This color denotes vast colonies of biological organisms forming a mat over stone and stucco. The dark color on non-deteriorated surfaces directly below patches of biological growth is the result of staining, where water has run through and imparted the color of the growth below.

Higher forms of plant life are also found on walls. On the exterior wall of the North Bastion are small clumps of plants (visible as dark blotches in fig. 10); excess moisture runs down the face of the wall below each clump. The exterior of the north city wall is now covered by a black mat. Where water drips from the scupper, plants have taken root and are growing (fig. 11).

The expansion of root systems of large plants and trees can adversely affect sub-surface conditions of structures. On the exterior of the former Granados Battery of el Morro, small plants and vines have taken root in the structure (fig. 12).

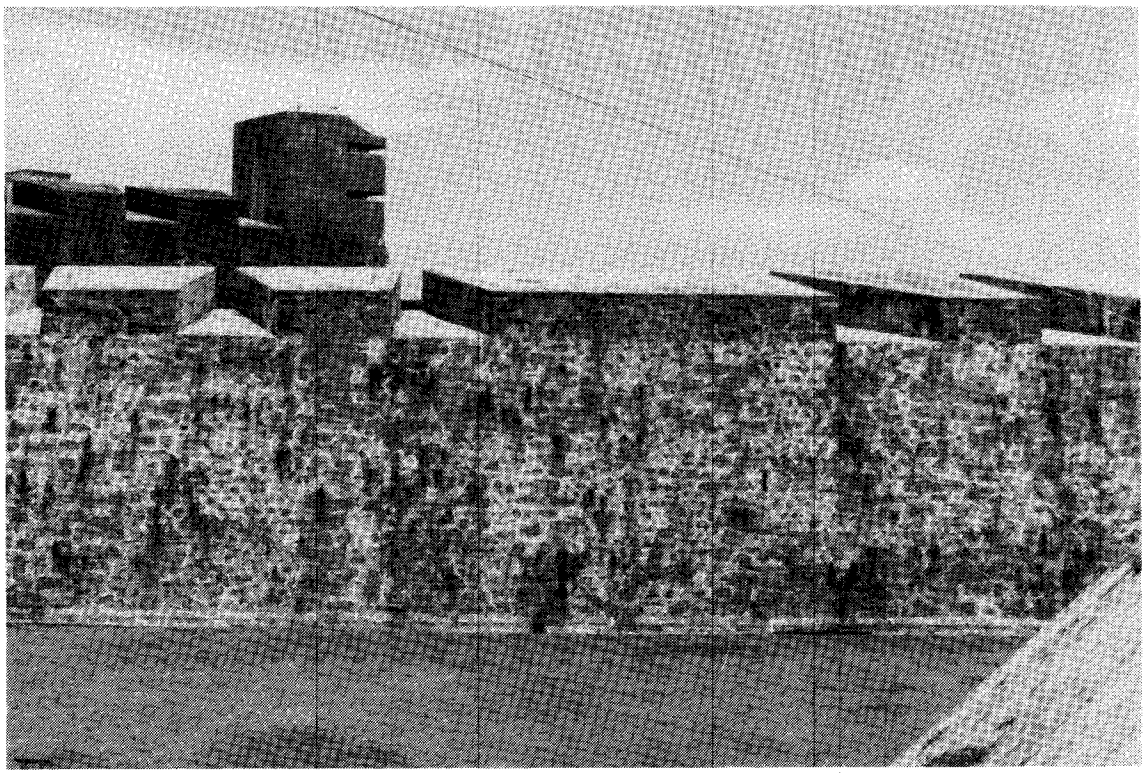


Figure 10. San Cristóbal, exterior wall of North Bastion. (Photo by J. Jacob, 1989.)

Figure 11. City Wall, north face by the cemetery. (Photo by J. Jacob, 1989.)

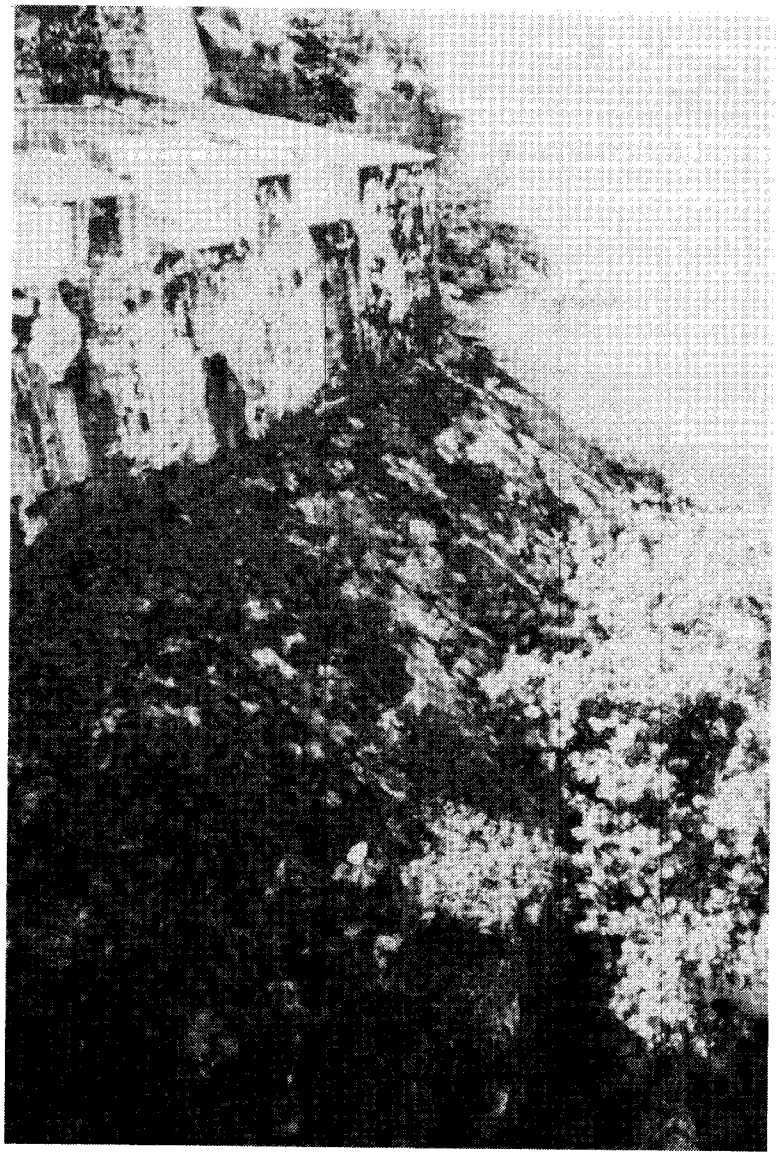


Figure 12. El Morro, former Granados Battery. (Photo by J. Jacob, 1989.)

Continued growth will contribute greatly to deterioration. A substantial amount of damage is being caused by trees growing directly on the city walls (fig 13).[7]

Structures that are located in areas not subject to landscape control (areas outside of the fortified walls, especially to the north) are becoming engulfed with vegetation. This may be causing, or hiding, structural deformation. In addition, the shade provided by large plants retards evaporation rates of moisture within a structure, often producing or augmenting moisture-related problems.

The growth of vegetation directly on structures has its origins in microbiological organisms. Air-borne spores are deposited on the rough surfaces of a building and with moisture and light, commence to grow. These organisms build the organic base necessary for the growth of higher plant forms.

An investigation of biological organisms was made by Robert J. Koestler (see Appendix E, Volume I). He found a variety of microbiological organisms on a sample of stone from el Abanico and discussed their detrimental effects on masonry: they produce mild organic acids,[8] retain moisture, and send their root systems deep into the substrate. The recent cleaning of the walls has removed the visible black mat, but most likely has done nothing to dislodge the root system, that will continue to grow and produce a new visible mat.

Human Impact

The human impact on buildings bears a large share in contributing to deterioration. General use, in the way of foot or vehicular traffic, leads to erosion. Likewise, the seemingly benign action of touching surfaces is abrasive and will also erode surfaces. Staining of surfaces will result from spilled beverages and vehicular oil and gas. Loads in excess of the original design can cause major building failure. Alterations can have negative or positive impacts because the introduction of new materials, systems, or elements may or may not be compatible with the original building. Improper maintenance can accelerate deterioration by allowing problems to continue or by adding repair materials that will be deleterious themselves. Often improper repairs are carried out with all good intentions, and it is only with time that they become visibly detrimental. War can have catastrophic effects on buildings.

Thousands of tourists come to visit the fortifications every year. Use is especially high at el Morro with visitation slightly lower at San Cristóbal. The San Cristóbal outworks are for the most part closed to visitors. Visitor use can be

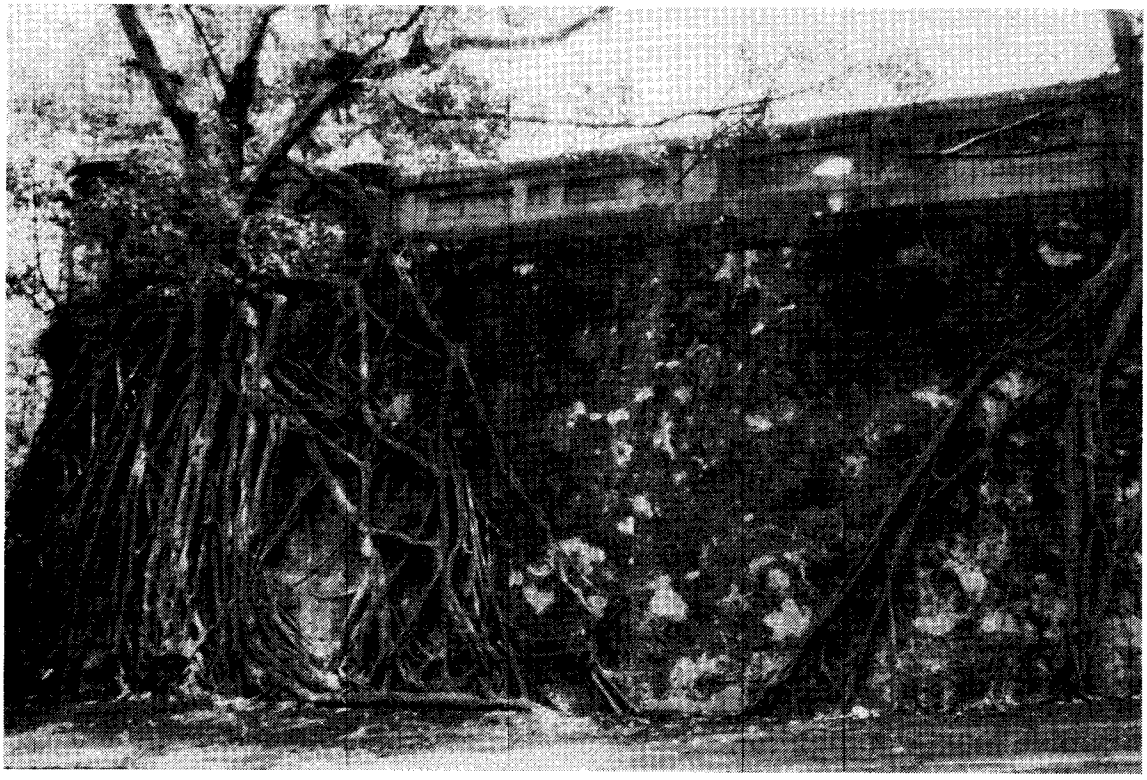


Figure 13. South City Wall, San Justo Bastion, administrated by the Commonwealth of Puerto Rico. (Photo by J. Jacob, 1989.)

characterized by pedestrian traffic on both designated pedestrian zones and on additional areas with easy access by climbing. The general wear and tear resulting from foot and hand abrasion is apparent. Graffiti is a problem.

Historically, human impact has consisted of military activity, recreation, maintenance, and restoration. To no surprise, the military function has had a deleterious impact. During the 1898 bombardment, portions of the fortifications were destroyed and projectiles were embedded in fabric that was not destroyed. One visible projectile protrudes from the interior wall of the former tower in el Morro. For a period of time, the U.S. Army used the Water Battery as a firing range. Alterations were made to historic fabric during both the Spanish and U.S. Army tenures.

Vehicular traffic has always been present in some form for transportation of cannon, ammunition and other supplies. Motorized vehicular traffic was common during the U.S. Army tenure and the early NPS years. Photographs show cars and trucks parked on the plazas of el Morro and San Cristóbal.[9] It is not known if this use affected the structure of el Morro and San Cristóbal or if the load was well within the confines of the planned limit. The main moat of San Cristóbal continues to be used as a parking area with resultant scaring from impact visible on scarped walls. Traffic passes by San Cristóbal and the city walls on a daily basis; the resulting vibrations could be affecting the structures.

As part of the recreational facilities for Fort Brooke, a golf course was constructed on the glacis of el Morro with the ninth tee located in the moat of Ochoa Bastion. Golf ball indentations are visible on the scarped wall.

The utilization of some buildings as office, interpretive, and storage areas by the NPS has necessitated the installation of climate control systems. Unfortunately, cooling needs have been met by the use of individual air-conditioning units. Although adding to the general comfort of employees and visitors, they have had deleterious effects on both interior and exterior fabric, including the alteration of fabric for installation. These units draw moisture from the internal air and collect the excess water; improper drainage is a problem. By creating a cooler and drier climate, moisture within the surrounding masonry mass migrates to the interior, creating a continuous cycle of moisture infiltration and evaporation. This recurring cycle has contributed to the dissolution of soluble materials and has caused the powdering of interior finishes. In addition, constant dampness has been advantageous for the growth of mold or other biological organisms.

Lighting systems installed in the fortifications have also resulted in several problems. Some alteration of building fabric has occurred. Cables, wires, and conduits are unsightly. Many that are no longer in use are still in place. The effects of light and heat produced by incandescent and fluorescent lighting was not researched for this report.

Plumbing systems were installed in San Cristóbal, el Morro, and the guardhouses at el Morro and el Abanico that have necessitated the removal and alteration of historic fabric. Problems in the systems result in leaking water and saturation of material. The coolers used for the water fountains have increased condensation in their respective locations and paving directly under water fountains is often wet.

Improper Maintenance

Improper maintenance has played a major role in the deterioration problem in the fortifications. Had the fortifications been constantly maintained with traditional materials, much of the deterioration seen today would be absent. Preservation efforts executed in the first half of the twentieth century used materials and methods that have proven to be less than advantageous. (Much of today's knowledge of improper materials has been gained only through retrospect.) One purpose of this report is to describe improper repair materials and methods in order to prevent their future use. In recent years, maintenance has been greatly improved.

Patching and pointing campaigns carried out by the U.S. Army and the NPS (up through the 1970s) made use of compounds with high-ratio portland cement (here called simply "cement") binders. The use of cement as the principle binding agent was common in the first two-thirds of this century and has proven to be extremely detrimental to buildings. (Lime was the principle binding agent for mortars in the fortifications from the sixteenth through the nineteenth centuries. In the last ten years, cement/lime combinations have been commonly used for binders.) Evidence of deterioration due to cement patches or pointing is rampant throughout the fortifications.

Cement cures to be quite dense (far denser than lime mortars) and a cement mortar will hinder the evaporation of water vapor from a wall mass. Moisture within a wall is diverted in its evaporation path to the surrounding stucco or stone (the softer materials). If patches are large, evaporation may be greatly retarded and a wall may acquire a high moisture content. Moisture measurements were made of cement patches and surrounding original stucco. As to be expected, measurements showed sound stucco and patches to be

the driest and deteriorated stucco surrounding patches to be the wettest.[10]

Throughout the fortifications, cement patches are characterized by a loss of original material around the perimeter where the interface between the two has failed. Cementitious materials shrink while drying (cement has a greater degree of shrinkage than lime), and even though it may not be apparent, small voids can occur at the patch/substrate interface. This, coupled with different water vapor transmission rates, will create a zone (at the perimeter) where salt crystallization is more likely to occur. The resulting erosion will enlarge voids. In addition, cements are a source of salts in themselves, and it is possible that these have migrated out of each patch into the surrounding material.

Many patches are characterized by small plants growing around their perimeters due to the excess moisture and deteriorated stucco in these locations. Although the patches in figure 14 were installed in the 1980s and have a high lime ratio, their recessed position and denser mass have produced a similar effect to cement.

The mortar that was used in the late 1930s facing of the banquettes and merlons on Santa Barbara Bastion has outlasted the masonry units it was originally bonded to (fig. 15). A combination of soft brick and dense cement mortar have created fins, marking voids where brick has eroded away.

Patches on the lighthouse now stand proud of the fabric they once abutted (fig. 16). Deterioration has, in fact, continued behind many of these patches and can be discerned by a hollow sound when tapped. The finial on San Carlos was given a cement cap and a patch. A 1961 photograph shows the patch on the same plane as the surrounding stone; by 1989 the interface had begun to fail, making the patch apparently protrude from its substrate (figs. 17 and 18). Cement pointing on the exterior scarped wall of Santa Barbara Battery is far more severe in its associated deterioration (fig. 19).

Another example of improper maintenance is the twentieth-century use of paint, either as a restoration color or for protection of the substrate. Paint used has not always been historically accurate in color, type, and location. Present-day graffiti is frequently covered with paint.

During 1989 and 1990, the rip-rap at the toe of el Morro was greatly expanded by the U.S. Army Corps of Engineers. Erosion is a great problem in this location, and the new rip-rap will prevent the further undercutting of the structure. Massive boulders were placed around the toe, maneuvered by bulldozer and crane. Vibration could be discerned when boulders were

emplaced by the crane. During the winter of 1989, two cracks developed on either side of the south corner of the Water Battery; crack monitors were installed and it was immediately apparent that the structure was vibrating with each emplaced (or dropped) boulder and that the crack was widening. Soon thereafter, concrete was poured around the base of the wall to prevent the corner from falling out. It is not known what the total effects of this vibration are.

Catastrophic Damage

Although the design of the fortifications was guided solely by a military function, it has proven to be effective in withstanding catastrophic damage from hurricanes and earthquakes. The huge masonry mass has prevented structural damage from hurricanes, although smaller elements (doors, gates, and finishes) have suffered. Earthquakes have caused cracking, but to date (and as known), there has been no displacement of major elements and no apparent loss of structural integrity.

A cursory structural investigation of San Cristóbal and its outworks was made in 1986 by Todd Rutenbeck of the Bureau of Reclamation (a copy of the report is found in Appendix B, Volume I). Structural cracks were noted in the dungeon at San Cristóbal, the chapel, and the Officers' Quarters. Other cracks were noted but were not considered to be problematic at this time. Overall structural condition was assessed to be generally good and areas of localized deterioration were noted for the site.

After three years of monitoring cracks in the dungeon, chapel, and Officers' Quarters, their presence was considered to be the result of former earthquakes. The random nature of their patterns and the absence of dimensional change suggested this seismic activity.[11]

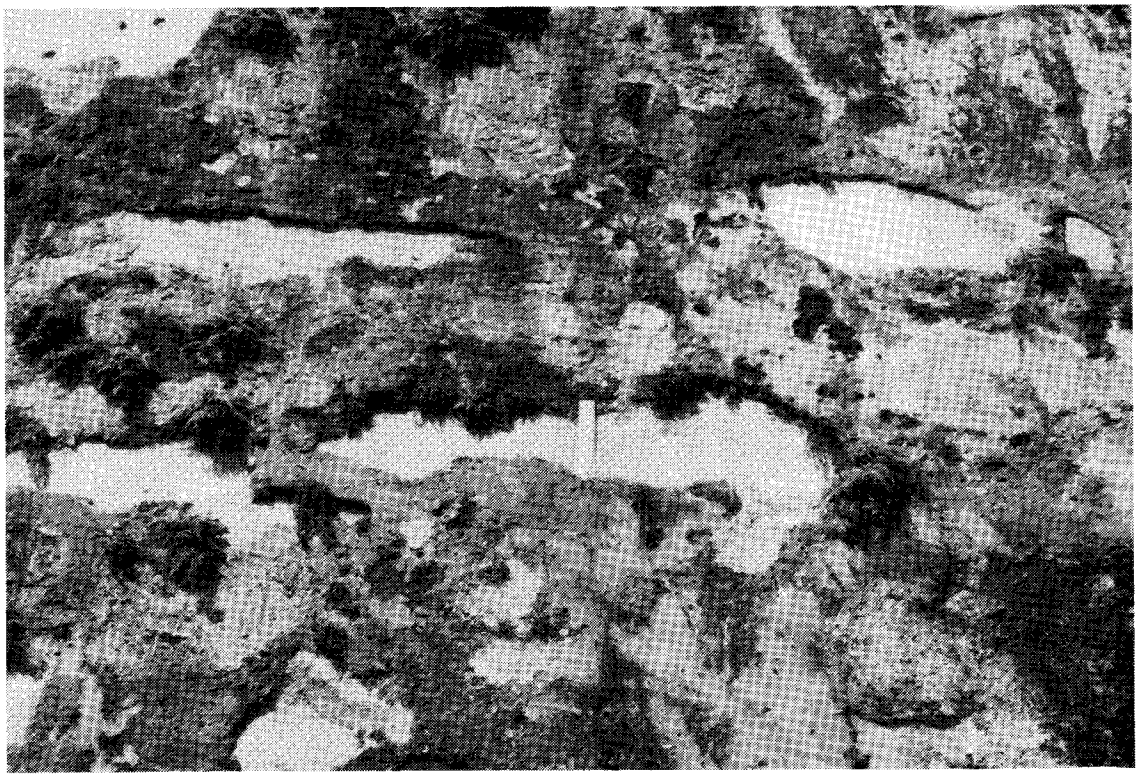


Figure 14. Ochoa Bastion, northeast wall. (Photo by W. Sedovic, 1988.)

Figure 15. Santa Barbara Battery, detail of merlon on north wall. (Photo by J. Jacob, 1989.)

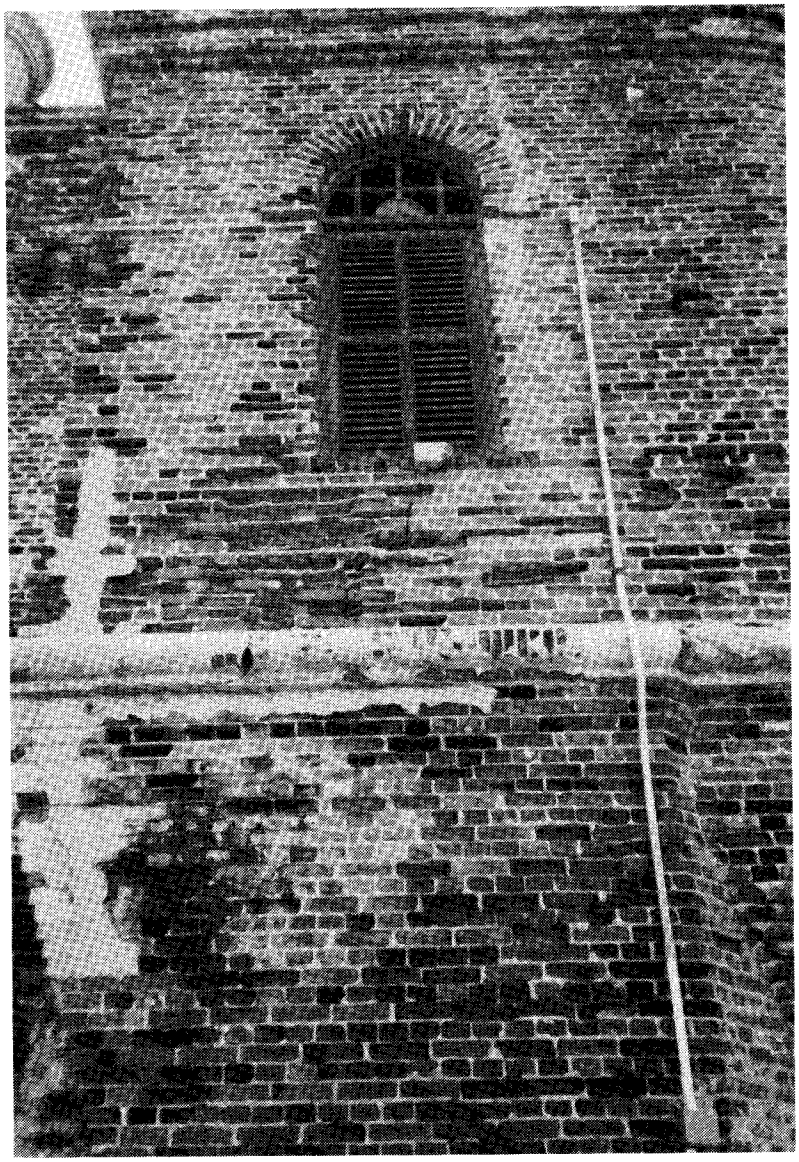


Figure 16. El Morro, lighthouse. (Photo by W. Sedovic, 1988.)

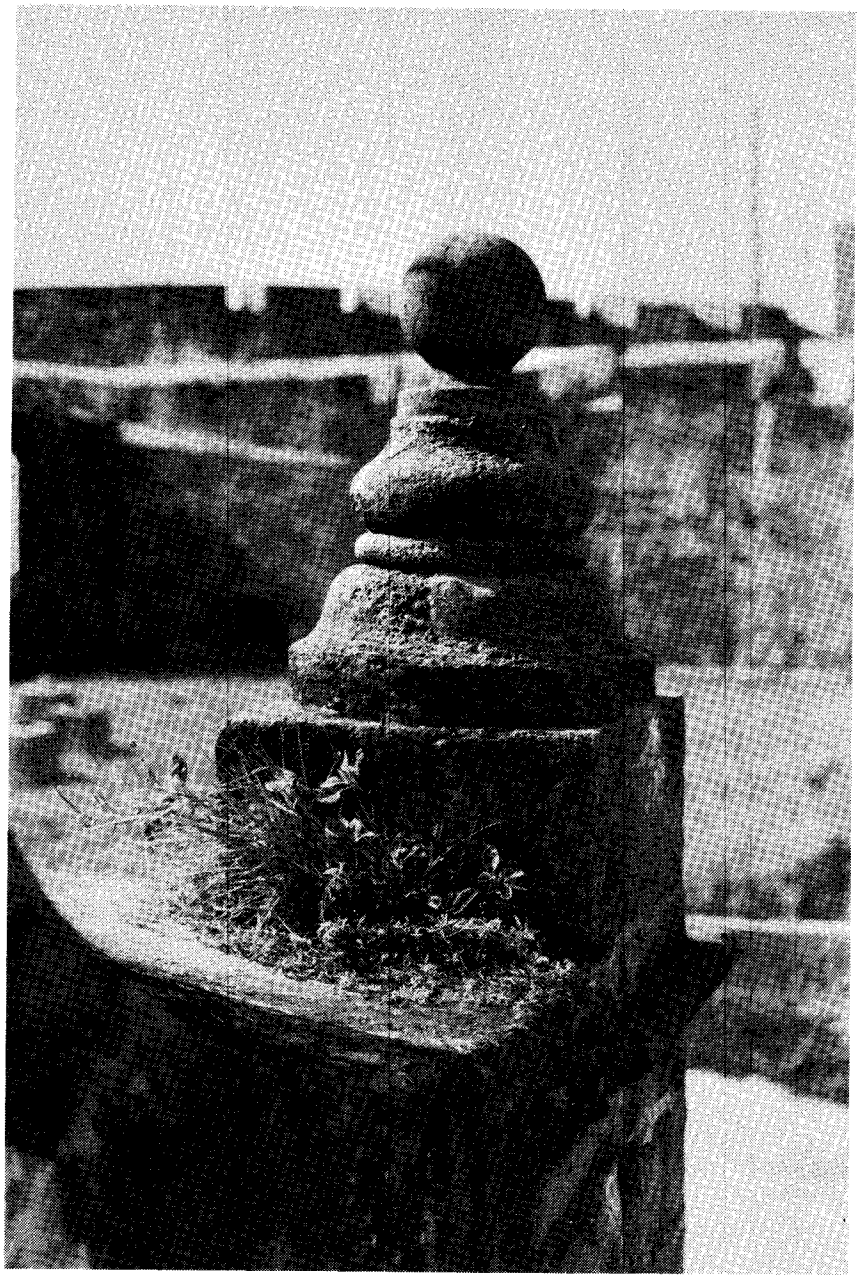


Figure 17. San Carlos, finial. (Photo by J. Boucher, 1961, HABS.)

Figure 18. San Carlos, finial. (Photo by J. Jacob, 1989.)

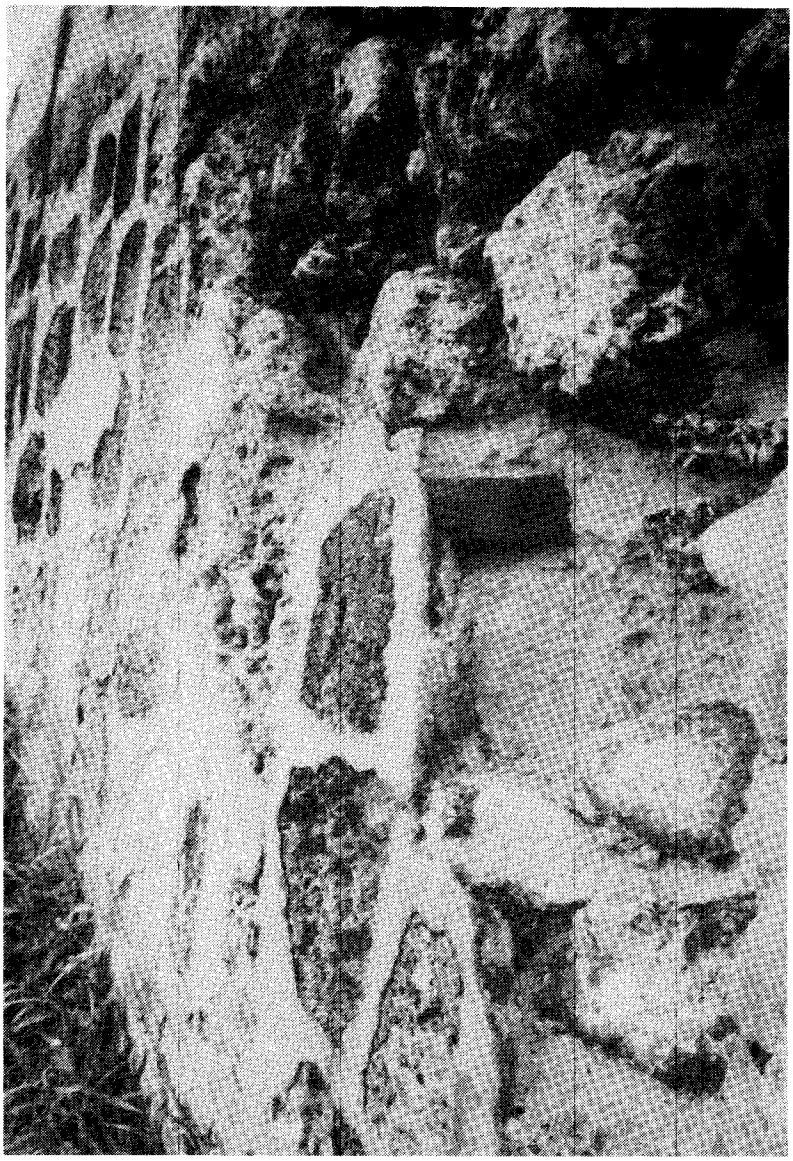


Figure 19. Santa Barbara Battery, exterior wall. (Photo by J. Jacob, 1989.)

CONDITIONS OF SPECIFIC FEATURES

Exterior Wall Finish

The condition of the yellow coating on exterior fortified walls varies from good to poor. Areas in good condition are characterized by an evenly covered surface. Areas in fair to poor condition are marked either by heavy streaking or by a pale color. In general, where the finish has been lost, the stucco substrate has become eroded.

The area in the best condition is at San Cristóbal on a small portion of the wall along the inside of a merlon adjacent to a World War II watch tower on the North Bastion. This area is protected from weathering and cut off from all pedestrian access. The finish is an even golden yellow ocher color with a slight sheen.

Loss of finish is due to abrasion (both natural and human), salt crystallization, and biological growth; rain may also be a contributing factor. Areas subject to greater weathering than others (ie. windward vs. leeward surfaces) and areas within pedestrian zones are more prone to deterioration from abrasion.

On the scarped walls of el Morro, the finish is characterized by streaking with color varying from dark to light. There are several explanations for this appearance, one or any of which may be the cause. It is possible that this may actually be a nearly original appearance with streaking resulting from application. Perhaps finishes were poured over the walls from above, and an even color was never achieved. (Areas displaying a more even color may have received a different type of application.) Such visually sloppy application is questionable however, when so many other areas of the fortifications are finished in a careful manner.

Streaking may be due to rain. If this were the cause however, one would expect a far greater loss than there actually is. It is also highly improbable that a water-soluble coating would have been used in the first place. A lipid component could soften with high temperatures (and be prone to creep) but again, if this were the cause of streaking one would expect far greater loss.

The apparent streaking of the finish may in fact be surface stains resulting from biological growth. A photograph dated 1900 shows the salient angle of Ochoa Bastion (fig. 20). The southeast wall still has most of its original surface stucco and finish. The black splotches designating deterioration and biological organisms all have, to a greater or lesser degree,

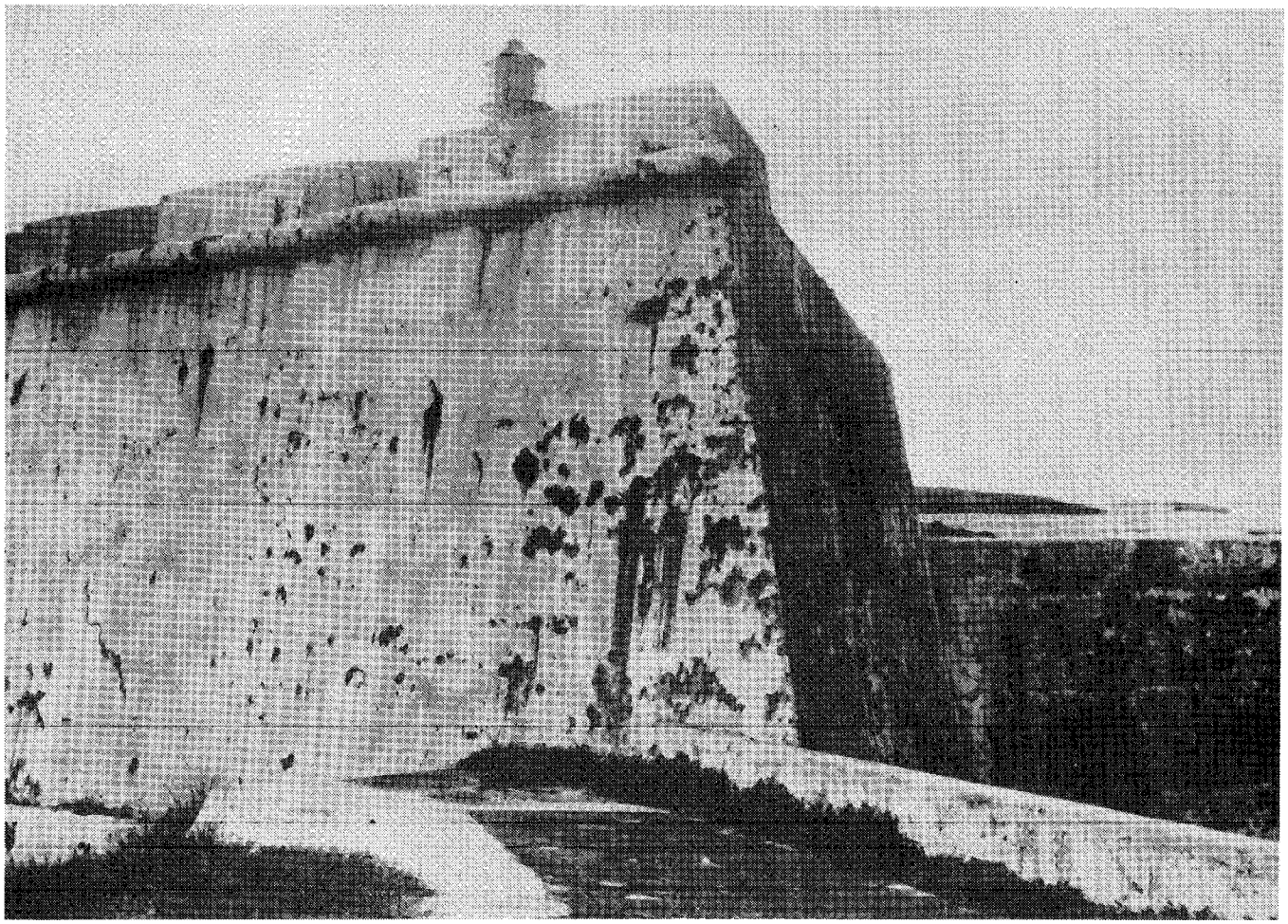


Figure 20. Ochoa Bastion, salient angle. (Photographer unknown, ca. 1900. San Juan NHS Archives.)

a dark streak below. The darker stains indicate that the original finish may have been lighter in color than the one protected area at San Cristóbal.

Variation in color (dark golden yellow ocher to pale yellow) could be due to different finish compositions or fading of pigment, although it is most likely that inorganic (and non-fading) pigments were used. It could also be due to a general loss of material.

Some areas of the fortifications have been painted, or resurfaced and painted, by the NPS (eg. walls facing the plazas of el Morro and San Cristóbal). The current finish of el Morro's plaza is in good condition; it is not known if it is the appropriate historical color or not. The paint on the quarters buildings at San Cristóbal is in less good condition with peeling and powdering evident (fig. 21). It is also not known if these colors are historically appropriate. The paint on the lighthouse is in poor condition.

Decorative faux ashlar finishes

Faux ashlar surfaces vary in condition from good to poor, generally corresponding to the condition of adjacent stucco and finish. Faux ashlar finishes in good condition are characterized by their readability and relatively little deterioration. Faux ashlar finishes in fair condition are readable but deteriorated; those in poor condition are barely readable or un-readable and badly deteriorated. The causes for deterioration of decorative finishes are those associated with stucco deterioration.

Faux ashlar surfaces in the best condition (good to fair) are found on the interior of the upper level of San Carlos and both on the interior and exterior of el Abanico.[12] There appear to have been faux ashlar surfaces on the exterior scarped walls and the interior plaza of San Carlos, as well as and the exterior of la Trinidad. These are barely readable and are in poor condition. Those in the rest of the fortifications are in fair condition. Painted finishes on cut stone have been nearly obliterated.

Some of the decorative elements of el Abanico have been covered with a cementitious paint in the same red color of the original feature. Many of the problems characteristic of cement patches are becoming evident here. This paint will be impossible to remove without damaging original material.

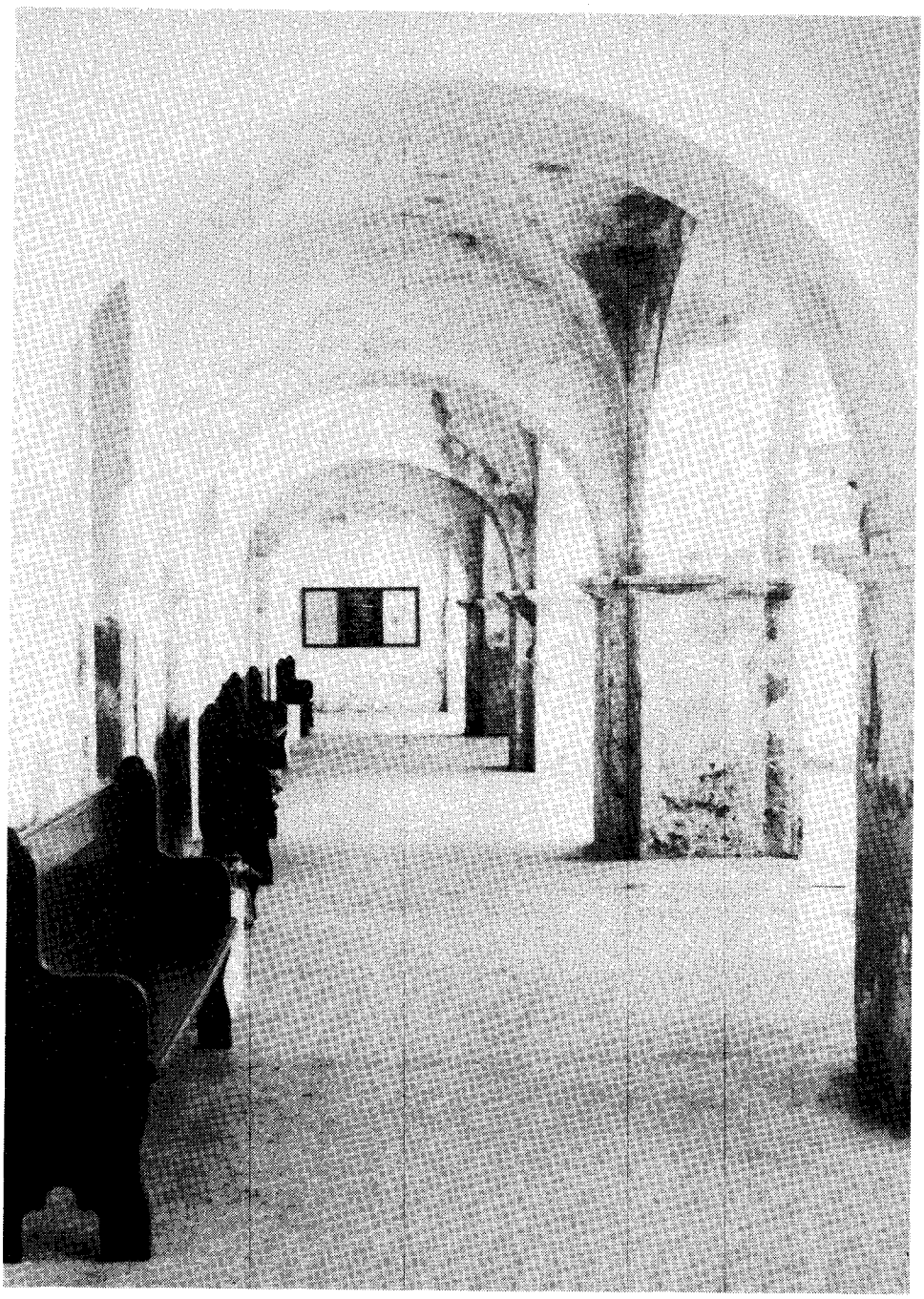


Figure 21. Officers' Quarters, San Cristóbal, arcade. (Photo by J. Berkowitz, 1986.)

Stucco

The condition of the surface stucco varies from good missing. Where the yellow finish remains intact, the stucco is in good condition. Where the finish is gone, erosion in various stages is evident, characterized by rough or pitted surfaces recessed from the original surface plane. In many places, erosion is at such at an advanced state that under layers of stucco and masonry units are exposed.

During the site research for this report, surface erosion was either obvious or determined to be in locations covered by the black mat of biological growth. Walls that had been cleaned of visible growth displayed a state of deterioration with surfaces quite rough.

The very outer surface of stucco is the most durable portion of the stucco.* Once the finish and outer surface layer of stucco are gone, the inner portion becomes prone to erosion and will erode more quickly than the outer layer. The under layers, the scratch coats and former surface coats, are composed of red/beige mortars and are characteristically friable, making them especially prone to erosion.[13]

The length of time required for a layer of stucco to become completely eroded is unknown. The problem was examined empirically with a comparison of historic and contemporary photographs (figs. 1-6). In the roughly fifty-year span of photographs of Austria Bastion's salient angle, deterioration seems to have progressed at a fairly constant rate. The rate of deterioration over a roughly ninety-year span on the sentry box and adjacent wall of Santa Barbara Battery also appears constant.

Causes for stucco deterioration are interrelated and have already been discussed. There are also some observed phenomena for which causes are not easy to determine.

The erosion of the surface layer of stucco (just like that of the finish) results from abrasion, salt crystallization, and biological growth. One would expect surfaces especially vulnerable to weathering to be in worse condition than those not, and in most cases this is the case. However, not all areas that show deterioration are so easily categorized, and often deterioration has occurred differentially in one area or

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** Stucco was floated as the final step in the application process. This functioned to compact the mass and bring the laitence to the surface, making the outermost layer denser than that below.

on one wall. Differential deterioration is probably due to both external phenomena and subsurface conditions.

Many walls have acquired a mottled appearance with some stucco remaining in good to fair condition and some in poor condition. The mottled appearance most likely has its genesis in wind-borne abrasives, the location of pinholes being governed purely by happenstance. Once deterioration began it commenced to spread, keeping its happenstance pattern.

The thickness of stucco, its composition (eg. materials and mixing procedure, salt content), and conditions of application (eg. degree of floating) contribute to stucco durability or susceptibility to failure. It is possible that conditions of masonry units and bedding mortar (as well as wall thickness) have led to this type of deterioration. Different densities, water vapor transmission rates, and salt contents could account for present surface conditions.

White stucco has an aggregate of beach sand. Beach sands should always be washed free of their salts when used in mortars. During the construction of the fortifications however, water was a precious commodity on the island of San Juan and it is possible that sand was not washed. Sands collected at a high point on a beach would be freer from salts than those lower, but it is not probable that enough of this purer sand could be gathered to stucco all fortification walls. It is most likely that stuccos were made with a salt content. The varying levels of salts in the original mixes may account, in part, for some deterioration patterns. Salt measurements of stucco samples were not made for this report.

On some walls, stucco has deteriorated to a greater extent over stone blocks and to a lesser extent over joints. Where faux ashlar was employed, it is possible that faux joints were somehow compacted to a greater extent than faux blocks (perhaps the entire surface was floated and the joints then trowled) and therefore, have survived to a better extent. It is possible that faux ashlar surfaces covered more areas than is now considered, and where this specific pattern of deterioration exists, such a finish once existed. Where a decorative surface was not employed, deterioration must have a strong link to subsurface conditions.

Another type of differential deterioration is where stucco has deteriorated to a lesser extent over the blocks and to a greater extent over the joints. This is quite common, and in advanced stages of deterioration, joints have become recessed. Subsurface conditions could be contributing to this pattern, with the opposite situation occurring than that where stucco over blocks has deteriorated more quickly.

Areas subject to constant wetness are prone to deterioration. This is apparent under the scupper on the exterior side of the north wall by the cemetery (fig. 11). Small plants are growing right in the path of flowing or dripping water. Areas not well drained are also prone to deterioration and biological growth (eg. at the junction of the top of the wall and the finial on San Carlos, fig. 18).

On the exterior of Santa Barbara Battery, on the harbor side, and on the exterior of the ramp connecting Carmen and Mercado Bastions, eroded and non-eroded surfaces are defined by a linear demarcation. In both locations, the pattern of stucco deterioration denotes a change in structure. On Santa Barbara Battery, the junction of the merlons and the scarped wall mark the line of deterioration. On the ramp, the junction of the top of the early-eighteenth-century portion and the late-eighteenth-century covering marks the line of deterioration. In both locations, stucco is in far better condition above the line. Assuming that behind each wall surface is a structure of stone, mortar, and earth and rubble infill, and that all walls are similar in this respect, then there must be some dissimilar element or some phenomenon that is causing such deterioration patterns.

It is not known why adjacent areas of stucco, on the same wall with the same exposure, behave in such different manners. However, several hypotheses can be postulated.

It is quite likely that different subsurface conditions exist that have now become apparent with the deterioration of the surface. It is possible that in these locations, stuccoing was carried out at two different times. It is also possible that the stucco is of varying composition (eg. salt content, degree of mixing) or application (eg. methodology of floating, weather conditions). Merlons on Santa Barbara Battery were constructed with thinner stone blocks than scarped walls; this may be affecting deterioration. It is not known what the constituents of the building fabric below the stucco on the ramp are.

During construction, water vapor-borne salts were absorbed by masonry units. If the merlons and ramp were constructed well after the walls had been built, they would have a lower salt content. It is possible that subsurface salts are in part responsible for deterioration today. Perhaps salts are responsible for other areas of stucco deterioration as well.

Stucco deterioration has occurred in areas adjacent to cement mortars or patches. While the mortar or patch remains in good condition, the surrounding original stucco has been subject to accelerated deterioration, especially at the interface between the two.

Hormigón

Hormigón varies in condition from excellent to poor. Only small areas exist in excellent condition and these are found in corners and adjacent to walls where foot traffic is minimal. Hormigón in good condition is fully intact but lacks its original surface coating. Hormigón in poor condition has become eroded with severe cases exposing the rougher under layers.

Hormigón surfaces are affected by weathering in much the same way as stuccoed surfaces; they are especially susceptible to erosion from hard rains. On the terrepleins, foot and vehicular traffic have contributed greatly to deterioration.

Remains of hormigón on the tops of merlons have deteriorated in a way different from that of the terrepleins. Erosion is quite irregular and is characterized by deeply etched circular patterns (fig. 22). These patterns are most likely the combined result of hard rain and unseen differential densities resulting, perhaps, from the circular motions of floating. Perhaps this same phenomenon occurred on the terrepleins, but due to hazardous walking conditions, rough areas were covered over.

Gutters were originally lined with hormigón, providing a smooth surface to facilitate the drainage of water. By now, much of the hormigón is gone seriously impairing the functioning of exterior gutters. (That part of the drainage system situated internally was not examined for this report.)

Cement patches have been used extensively for repairs. Almost all patches appear to be in good condition. In many locations however, the hormigón at the interface of the patch has deteriorated and retains rain water in small pools after the rest of the terreplein has dried.

There are many cracks in hormigón. Cracks could be the result of earthquakes, stress from loading (especially vehicles), or differential settlement or shifting of the masonry mass beneath. Many of these are filled with dirt and host to growing grass.

Stone

With the exception of exposed bedrock foundations, all structural stone was originally covered with stucco, serving as a protection from weather. Where stucco is no longer present, exposed stone is covered with a black mat of

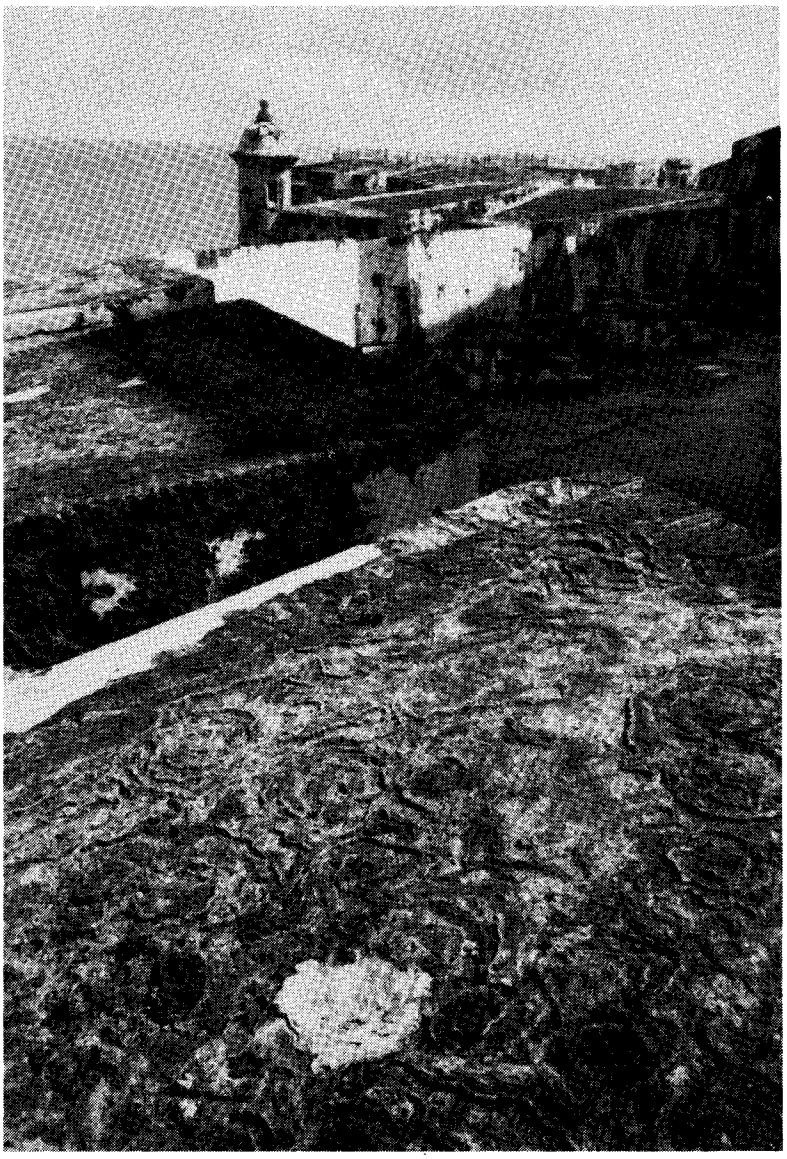

Figure 22. Santa Barbara Battery, merlons on the south side. (Photo by J. Jacob, 1989.)

biological growth. Stone blocks now vary from good to poor condition with the majority in good condition. Although the biological factor is severe, stone is considered to be in good condition if it maintains its structural integrity.

In areas where prolonged dampness is prevalent, dissolution of the calcium carbonate component of stone is occurring. When the base of the scarped wall of Ochoa Bastion, (facing the entry to el Morro), was probed, the stone powdered. This problem can have drastic effects. Although the structural integrity of the fortifications is not affected now, with continued deterioration the situation will change.

Bedrock foundations by the ocean are eroded from exposure to wave action. El Morro and el Espigón face this problem; a rip-rap has since been constructed in front of el Morro and el Espigón has been repaired numerous times. Because areas affected by wave action are not easily accessible, the extent of damage or potential damage in these areas was not investigated.

Cut stone elements appear to have been left without stucco; it is difficult to determine if they were originally painted. These elements (eg. finials on San Carlos, gateways, some architraves, perhaps the corbled portions of sentry boxes) appear to be in good condition. Weathering has occurred, but has affected elements evenly, thus retaining original profiles.

The marble floor tiles in San Cristóbal and el Morro are somewhat eroded from constant pedestrian use, but are in overall good condition. The dark blue gray pavers (composite stone) are also somewhat eroded. They appear to date to two periods of time; newer pavers are in better condition than older.

Brick

Most brick used in wall construction and in lining gutters was originally covered with stucco or hormigón. Brick paving and ceramic roof tiles were not covered. It appears as if interior brick structures (eg. stoves, latrines) were not covered either. Brick installed during the Spanish tenure varies in condition from good to poor; brick installed during the U.S. Army tenure also varies from good to poor.

Brick dating to the Spanish tenure is primarily found edging banquettes and merlons and was originally covered with stucco (fig. 23). Where stucco has worn away on tops of merlons, brick remain in good condition with the mortar exhibiting loss. Exposed brick on banquettes is eroding due to heavy pedestrian traffic.

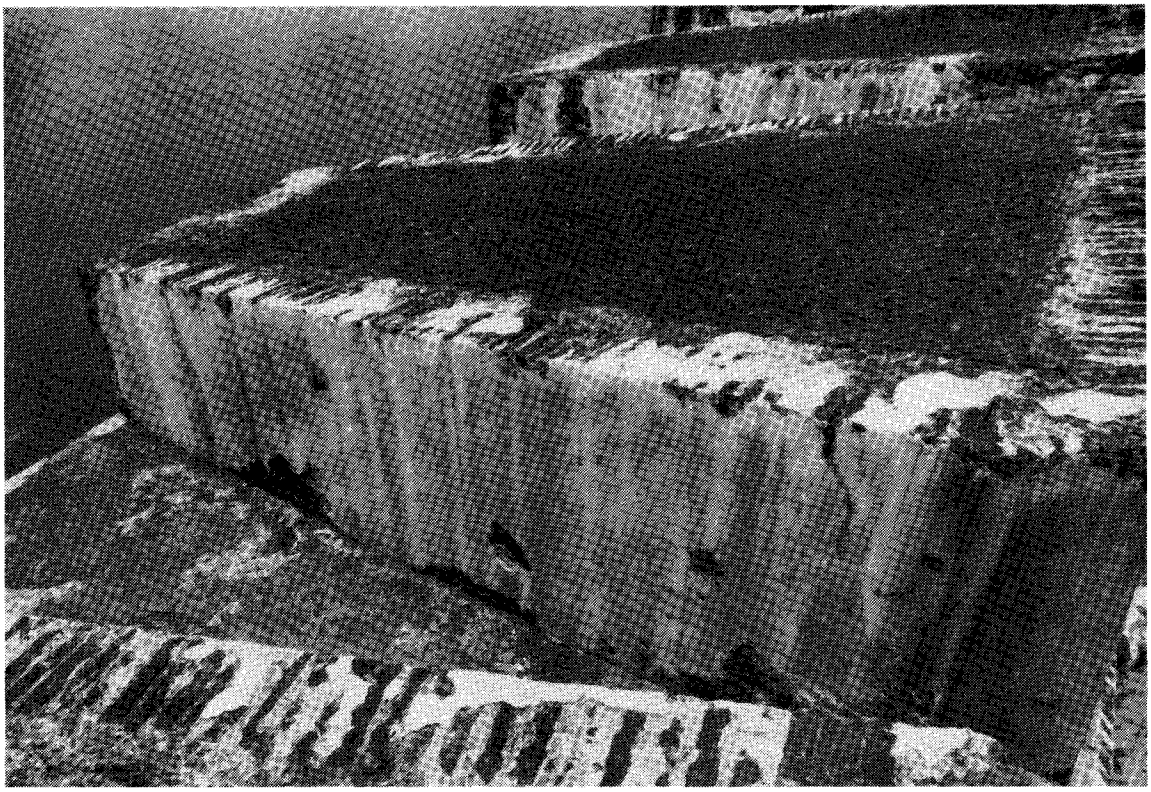

Figure 23. Santa Barbara Battery, merlons on the south side. (Photo by J. Jacob, 1989.)

Brick found on gun track perimeters is in generally poor condition (replacement brick is in good condition). Poor quality brick, abrasion from foot traffic and weathering, and a susceptibility to wetness are factors that have contributed to this condition. On Santa Barbara Battery, gun tracks are marked by both badly eroded brick and mortar, with the mortar having deteriorated first (fig. 24). The differential erosion of the brick indicates that there are slight variations in quality. After rain storms, water pools on top of the brick.

The most dramatic deterioration of brick is found on the lighthouse and many of the banquettes on el Morro. In many cases, brick have deteriorated to such an extent that they are almost completely lost. The visual effect of the loss is heightened by the remaining mortar, standing proud.

There are a variety of causes that have led to the deterioration of brick in the lighthouse, most of which have been outlined already. This type of deterioration is typical of soft brick and high-ratio cement mortars (often visible on buildings that have been pointed as part of a repair or restoration). The mortar of the lighthouse is denser than the brick, but it is much softer than a high-ratio cement mortar. Regardless of its constitution, moisture within the masonry mass has evaporated through the brick with resulting deleterious effects. The older portion of the lighthouse is in far better condition and it is presumed that brick are of better quality (or harder) and the mortar is as dense, or less dense, than the brick. Brick on the upper portion that have not eroded, must also be of better quality than those that have eroded.

The many coats of paint still clinging to non-deteriorated portions of the lighthouse testify to the fact that the structure was painted and repainted on a frequent basis. A photograph from 1961 depicts a painted structure, vastly different in appearance than what exists today (figs. 25 and 26). In the 1961 photograph, some brick deterioration is evident (the painted surface is not entirely smooth and even). The paint protected brick and mortar from weathering and moisture absorption. Once the paint wore off, brick deterioration must have occurred at a rapid rate; it is not known if deterioration continues at this same rate or at a lower rate today.

After heavy rain, pools of water remain on the upper level (just below the light) of the lighthouse. What water does not evaporate saturates the fabric, adding to the deterioration of the structure below.

Brick edging merlons and banquettes on Santa Barbara Battery are badly deteriorated (fig. 15). These were installed by the

U.S. Army in the late 1930s with a high-ratio cement mortar. The softer brick have almost completely eroded away.

Roof tiles appear to be in good condition. Floor tiles in San Cristóbal are also in good condition with only small chips marring appearance.

All brick treads and risers of stairways appear to be reconstructions of this century. The brick vary in condition from good to fair; erosion from pedestrian traffic is evident in some locations. The wooden nosing is badly deteriorated in some places as well.

Mortar

Prior to the twentieth century, mortars with a predominantly lime binder were used. In general, those examined in the fortifications are soft with some being quite friable. When protected from moisture and weathering (stucco on the exterior), mortar remains in good condition. However, when exposed to a mechanism for deterioration, these mortars will rapidly erode. Eroded conditions are visible throughout the fortifications.

Not all interior walls and vaults were stuccoed. In these areas (eg. tunnels, some vaults at el Morro), some loss of mortar is evident. Most deterioration has occurred through powdering, where binder at the surface has become dissolved and leached out. Voids between brick or stone appear to be an original condition where not all joints were filled to capacity with mortar.

Concrete

The concrete World War II structures appear to be in generally good condition. A full investigation however, was not made for this report.

Sod

Where sod is used in the fortifications (eg. San Cristóbal, el Abanico, la Trinidad), it is in good condition. However, sod can promote deterioration. Sod holds high quantities of moisture that will evaporate out through the surface as well as percolate down through the sod to masonry materials below. It is possible that subsurface conditions are quite damp. It is not known how this dampness is affecting material and structural integrity.

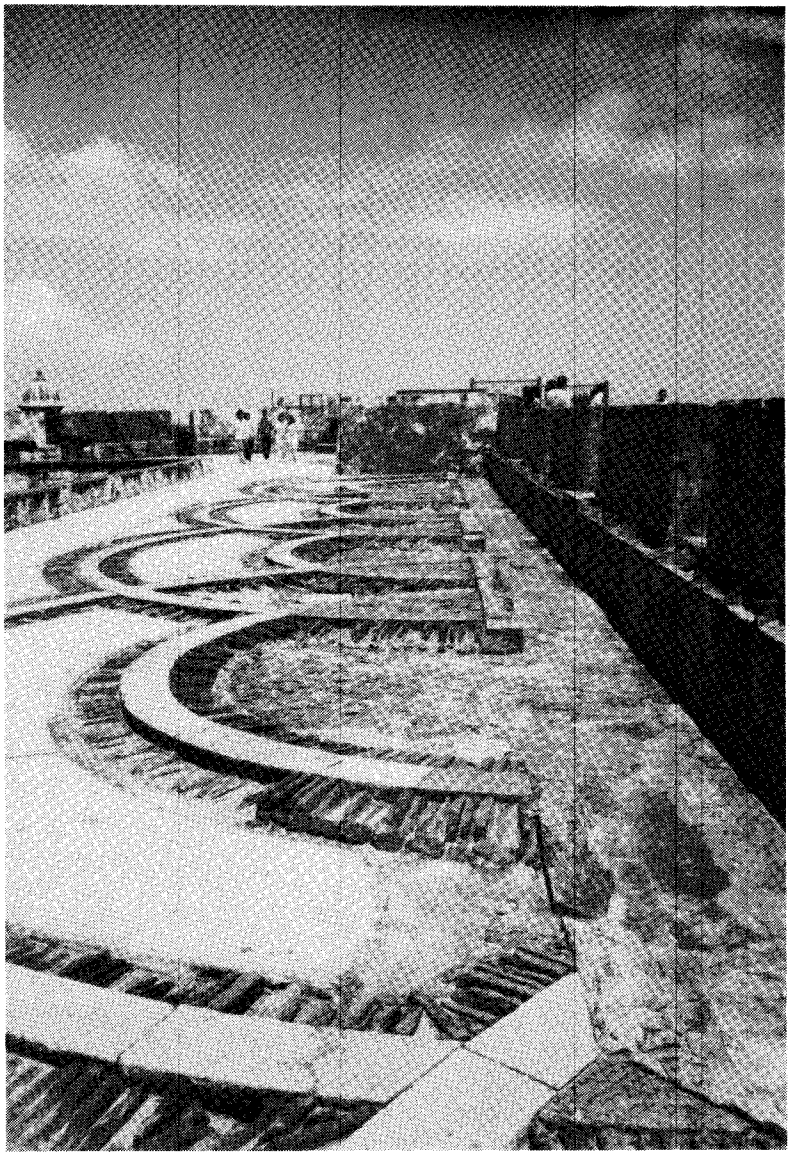

Figure 24. Santa Barbara Battery, gun tracks on the north side. (Photo by W. Sedovic, 1988.)

Figure 25. El Morro, lighthouse. (Photo by J. Boucher, 1961. HABS 16616.)

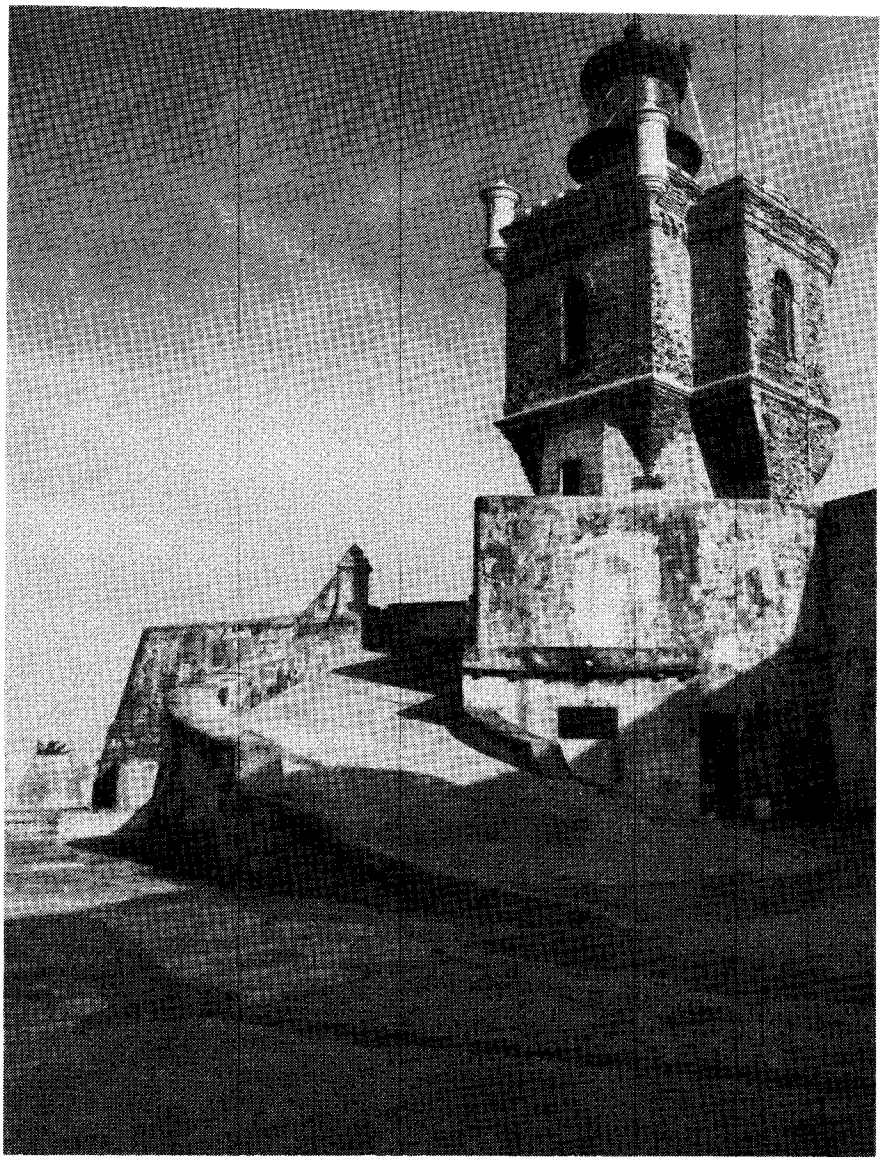

Figure 26. El Morro, lighthouse. (Photo by J. Jacob, 1989.)

Interior Stucco and Finishes

Original finishes on interior masonry walls are in fair to poor condition. Twentieth-century finishes are in good to poor condition. The most obvious problems are powdering, flaking, and loss. Original and twentieth-century stucco on interior masonry walls varies in condition from fair to poor, with powdering and loss evident.

As exterior surfaces become eroded and prone to water infiltration, interior surfaces are eventually affected. Moisture that migrates through a wall mass will eventually evaporate through an interior surface. The dissolution of material, transportation of salt ions, and continual migration cause the degradation of both stucco and painted surfaces; frequently the paint/substrate interface is affected first. Biological growth (perhaps a form of mold) is present on some interior walls.

Graffiti and Illustrations

Incised graffiti is now black in color (biological growth) and the original lines have increased in size due to erosion. Geometric designs incised in still-wet stucco (eg. el Abanico) are in good condition.

The drawings of ships (executed in red) found on Austria Bastion, Santa Elena Bastion, and Santa Barbara Battery are quite light in color. This light color may be original, or simply a faded (or weathered) version of the original. General stucco deterioration has caused the most severe deterioration of the drawings resulting in complete loss of original images in some areas.

Illustrations executed with black paint on some interiors (eg. the San Cristóbal cisterns, the dungeon of San Cristóbal, and the tower room of el Morro) are in poor condition. Both the stucco substrate and paint are powdering and a great deal of loss has occurred. A photograph from ca. 1938 depicts the painting of St. Christopher in the cistern of San Cristóbal (fig. 27).[14] Some deterioration is evident; today the image is nearly completely obliterated (fig. 28).

Powdering of paint and stucco is due to a high moisture content in the walls and the rooms themselves. Human abrasion is also a problem in areas accessible to such abrasion (eg. the tower room of el Morro). The drawings of ships in the dungeon of San Cristóbal are covered by a polycarbonate panel; this panel is trapping moisture and may be contributing to deterioration.

Figure 27. San Cristóbal, painted figure in cistern. (Photo by T. T. Waterman, ca. 1938. San Juan NHS Archives.)

Figure 28. San Cristóbal, painted figure in cistern. (Photo by J. Berkowitz, 1986.)

Glass Windows and Lighthouse Light

Windows in casemates now serving as offices or interpretive centers are in good condition. Windows in the lighthouse vary in condition from good to poor. Those in poor condition are cracked or have pieces missing (there are also a few bullet holes). Cracking of windows has been primarily caused by alterations to the frame (the insertions of screws into the mullions); bullet holes are the successful results of recreational target practice. The light appears to be in good condition.

Wooden Elements

Wooden elements date to the Spanish tenure (the earliest being the late-eighteenth century) and to the twentieth century. Conditions vary from good to poor. Those elements that have been continually painted and thus protected from weather are in good condition. Elements that have not been painted, or worse, have been stripped of their paint, are in fair to poor condition. Fragments dating to both the Spanish tenure and the twentieth century are, by their very nature, in poor condition.

Doors, gates, shutters, and their enframements dating to the Spanish tenure were stripped of paint in the 1970s. The removal of paint from all wooden elements has eliminated historical finishes and their protective qualities. Elements that remained in good condition throughout their first century and a half of use are now subject to the detrimental effects of the environment.

Gates and their enframements, bridges, and walkways dating to the twentieth century that have been painted vary in condition. Where paint is still intact, the wood beneath is assumed to be in good condition. Where paint has failed, the wood beneath is weathered. The "gun rack" at el Morro, presumed to date to the late-eighteenth century, has remained painted over the years and is in good condition.

The forces of deterioration that affect masonry materials also affect wood.[15] Natural weathering, human impact, and moisture can all lead to degradation of wood. Being an organic material, wood is also susceptible to attack from insects and biological organisms.[16] The hard, tropical woods used in the fortifications have much greater resistance to weathering and biological attack than other woods, but they are by no means resistance-free.

Weathering of wood is a condition occurring on exterior surfaces. Wood decay is a more serious condition than weathering, and occurs throughout a wooden element.

The process of weathering is a complex phenomenon, with various components acting in synergy to produce deterioration. Wind, rain, wind-borne abrasives, and ultra-violet light all contribute to deterioration. Ultra-violet rays from the sun decompose lignin and some extractives of wood. Wind and rain blow or wash decomposed lignin away, leaving a layer of cellulose fibers. With the lignin gone, surface fibers are blown or washed away, exposing fresh lignin to the sun. The process then begins again. The surface of weathered wood frequently harbors fungi and mildew which are responsible for the gray, or mottled gray color, of weathered wood.

Wood decay will result when conditions are damp and warm. Numerous species of biological organisms, both botanical and zoological, thrive with these conditions and will essentially eat away at wood. Loss of structure is the end result.

Wood is also prone to deflection with natural drying and change in environmental conditions (primarily increases or decreases in moisture levels). With stress, wood will check, crack, swell, shrink, and warp.

The daily abrasive action of human handling has caused damage to wooden elements. Those elements most affected are railings, stair nosing, doors, shutters, and door and shutter enframements.

Metal Elements

Metal elements vary in condition from good to poor. Iron elements that are painted are in good condition; iron elements that are not painted have rusted. Bronze elements are in good to fair condition. Chain link fences appear to be in good condition.

Some iron fasteners (eg. hinges, nails) appear to date to the late-eighteenth century, or to the period when doors and shutters were installed. These are recognized by their appropriate placement on the door and frame and the absence of ghosts of previous fixtures. These original elements have become severely rusted. Replacement elements (dating to this century) that have not been painted have also rusted.

All iron or steel features that were never painted, or whose paint has deteriorated, have rusted. These include gun tracks and all related fasteners attached to walls, merlons, and terrepleins. Where iron has been painted, and the paint has

not failed (especially on grilles) the material is in good condition. Bronze elements that have been oiled on a periodic basis appear to be in good condition. Those that have not been maintained have begun to corrode.

Metals are corrosively affected by water. Salt water is especially damaging as it accelerates the corrosion process. In addition, water also acts as a vehicle for the staining of non-metallic surfaces with corrosion products.[17]

NOTES

1. A study of el Cañuelo was not made for this report.

2. Conditions following Hurricane Hugo (1989) were not assessed for this report. The cleaning of the walls had commenced at the time of the last site visit; conditions discussed in this report are primarily those prior to cleaning.

3. These are outlined in the following historic structure report: Edwin C. Bearss, San Juan Fortifications, 1898-1958, San Juan National Historic Site, Puerto Rico (Denver: U.S. Department of the Interior, National Park Service, Denver Service Center, 1984.)

4. The following sources describe deterioration of buildings and materials:

Amoroso, Giovanni G. and Fassina, Vasco. Stone Decay and Conservation. Materials Science Monographs, 11. Amsterdam: Elsevier Science Publishers B.V., 1983.

Feilden, Sir Bernard M. Conservation of Historic Buildings. London: Butterworth and Company, Ltd., 1982.

Wilson, Forrest. Building Materials Evaluation Handbook. New York: Van Nostrand Reinhold Company, 1984.

Winkler, E.M. "Decay of Stone." In Conservation of Stone and Wooden Objects. Preprints of the Contributions to the New York Conference, 7-13 June 1970. London: The International Institute for Conservation of Historic and Artistic Works, 1970.

5. Acidity of rain and pollution counts were not made for this report.

6. Porosity was based on visual examination.

7. Even though this condition exists outside of the NPS domain, it is included here as an example of an extreme situation.

8. An elemental analysis of the outer surface of a sample of stucco from el Morro was made in 1988 by Laurence Leonard (see Appendix F). This analysis identified sulfur on the outer surface of a sample, and in the draft report on "Recommended Treatments for Masonry Preservation" prepared by HPC, the sulfur was identified by the author to be part of a gypsum crust. While it is true that gypsum is created by the interaction of lime and sulfur, a common occurrence in heavily polluted environments, the sulfur on the

III. RECOMMENDATIONS

DEVELOPMENT OF A STRATEGY FOR TREATMENT

General Approach

The following section outlines a strategy for the preservation of military fortifications at San Juan National Historic Site (SAJU NHS). The recommendations are based upon exhaustive research into the developmental history of the structures, the nature of remaining historic material, and analysis of causes leading to material deterioration. In broad terms, the recommendations are as follows:

1. All historic fabric from the Spanish period, the lighthouse of el Morro, and the twentieth-century harbor defense system should be preserved. Emphasis should be placed on preservation of material and features from the Spanish II Period (ca. 1760-1835), as well as any surviving historic fabric from the Spanish I Period (ca. 1539-1760).

2. Restoration should consist primarily of removal of non-historic features and reestablishment of protective wall coatings.

3. Rehabilitation should focus primarily on issues of safety and security. Accommodation of facilities for visitors and park operations should be considered when space in non-historic or less significant structures is not available.

Legal and Policy Considerations

The recommendations contained in this report have been developed in accordance with federal preservation law and NPS policies, guidelines and standards for treatment of cultural resources. Preservation law calls for federal agencies to preserve eligible National Register structures under their jurisdiction "to the maximum extent feasible." In cases involving National Historic Landmarks, the law mandates preservation "to the maximum extent possible." Although the fortifications of San Juan are not currently listed as Landmarks, they have been designated a World Heritage Site and should probably be managed within the stricter provisions of the law.

A number of different treatments are possible and a major purpose of this document is to identify the most appropriate course of action specifically for the San Juan fortifications. This purpose is consistent with current management policy:

> The fundamental question of which treatments will best provide for the preservation and public enjoyment of

> particular cultural resources will be decided through planning. No treatment project will be undertaken unless supported by an approved proposal, plan, or report appropriate to the proposed action. The significance of the resource, its condition, its interpretive value, its research potential, and the availability of data will all be weighed in determining the appropriate treatment. (NPS Management Policy, Chapter 5, p. 5, 1988.)

In general terms, the treatment preferred for most NPS structures is preservation. The focus of preservation is on maintenance and replacement in-kind of deteriorated materials.

Another major treatment alternative is restoration. The objective of restoration is to reestablish the appearance of a structure as it existed at some past date. To do this, later additions must be removed and missing features must be reconstructed. Because of the potential difficulties and high costs inherent in both demolition and reconstruction, preservation standards for restoration have specific requirements for documentation, identification of new features, and justification of need.

The third, and final, major treatment that applies to San Juan is rehabilitation. The purpose of rehabilitation is to improve safety, fire protection, function, energy efficiency and handicapped access. Rehabilitation is permitted by NPS policy but must be backed by suitable study to minimize loss of historic fabric and to maintain continuity with historic character.

Specific standards for use of preservation treatments are contained in NPS-28, the National Park Service guideline for Cultural Resources Management. These standards should be consulted during the implementation process regardless of treatment type.

Periods of Significance

Differentiation between historic and non-historic fabric is essential in the development of any preservation strategy. This process of identification must be grounded in a clear understanding of the historic associations ascribed to a significant structure. For the fortifications at San Juan, the associations are fundamentally of a military nature and can be divided into five time periods, as follows:

Spanish I (ca. 1539-1760)

> The first Spanish period takes the construction of fortifications from their initiation, through early

phases of development, to the point of major alteration and development. Remnants of this period are evident in the tower at el Morro, lower portions of San Cristóbal and el Morro, and the city wall facing west and south.

Spanish II (ca. 1760-1835)

El Morro and San Cristóbal were expanded and modified during the second Spanish period. In addition, the north city wall was built and the west harbor defenses were completed. The greatest degree of historic integrity and best representation of the history of military architecture are found in the fortifications still standing at San Juan dating to this period.

Spanish III (ca. 1835-1898)

The third period of Spanish development consisted largely of maintenance of earlier work and preparation for war with the United States. New gun emplacements were common additions to the fortifications during this period.

American I (ca. 1898-1940)

American jurisdiction over the San Juan fortifications resulted in (a) reconstruction of a damaged lighthouse on el Morro, (b) a program of repairs and maintenance, and (c) construction of new buildings and modification of older buildings as part of an American Army post called Fort Brooke. The only feature of significance left from this period is the lighthouse. All other remnants are considered non-historic due to the loss of historic integrity.

American II (ca. 1940-1961)

A new harbor defense system was created by the American military at the outset of World War II. Features of the system were incorporated into the existing Spanish fortifications. Fire control towers, operations centers, and gun emplacements were major features of this system. The system is primarily significant as a part of local history.

Features to be Preserved

As an example of eighteenth-century military architecture, the fortifications at San Juan are characterized by massive masonry walls, paved exterior areas for guns and movement of troops, and well protected interior spaces, typically for storage and quarters. The height, configuration and

interconnection between walls was particularly important as a reflection of military tactics and weapons.

In addition to the overall size and shape of the fortifications, there are a number of other features that deserve special attention in terms of preservation. Some of these features are particularly vulnerable to deterioration from human contact, weathering, and biological attack. The features can be divided into four broad categories: finishes, architectural details, military components, and utilities.

Finishes:

Exterior wall stucco, interior plaster, paving, wall paintings, and graffiti.

Architectural Details:

Moldings, stairs, gates, doors, windows, shutters, plaques, and chapels.

Military Components:

Gun emplacements, banquettes, ramps, scarps, counter-scarps, glacis, tunnels, and parapets.

Utilities:

Scuppers, drainage pipes, cisterns, cistern heads, and waste disposal systems.

Lighthouse:

Brick walls, lantern, light, stairs, generator room, parapet, and lantern dome.

Harbor Defense System:

Concrete batteries, fire control, and operations center.

Treatment Alternatives

Given a better understanding of the integrity and value of the San Juan fortifications, it is both possible and necessary to reconsider the direction given in the General Management Plan (GMP) for overall treatment of these historically significant structures. The GMP states that the interpretation of the Spanish period is of primary significance, but that the site will be preserved to its 1961 appearance. In addition to this option, there are at least four other major alternatives that deserve evaluation. The five basic treatment options are

summarized below in terms of their respective advantages and disadvantages.

1. Restore the fortifications to ca. 1540.

   Advantage: Would permit interpreting the site to the period of unquestioned Spanish supremacy in the Caribbean, and when the fortification of el Morro was begun.

   Disadvantage: Would require demolishing most extant historic resources; reconstruction would be extremely conjectural and costly, and inconsistent with GMP and NPS policies.

2. Restore the fortifications to ca. 1835.

   Advantage: Would facilitate the interpretation of the site at the time of the maximum defensive effectiveness during the Spanish period; and would focus on the primary associative value of the fortifications as a defensive historical site.

   Disadvantage: Would require demolition of some extant resources, e.g., late nineteenth-century Spanish construction, and other significant twentieth-century features, e.g., the lighthouse at el Morro and the harbor defense system; this would result in having to reconstruct some features that have already been removed. Reconstruction would be conjectural, costly, and inconsistent with GMP and NPS policies.

3. Restore the fortification to ca. 1898.

   Advantage: Would facilitate the interpretation of the site to the time last occupied by the Spanish; and would focus on the continuum of Spanish influence.

   Disadvantage: Would require demolition of some extant twentieth-century resources, e.g., the lighthouse at El Morro and the harbor defense system; this would result in having to reconstruct Spanish-period features that have been removed; reconstruction would be conjectural and costly; this alternative would be inconsistent with GMP and NPS policies.

4. Restore some features to their original date of construction.

   Advantage: Would provide an interpretive focus on the various periods of development within the continuum of Spanish and American occupation.

Disadvantage: Would create an incongruous setting for visitor experience and would hamper the interpretation of the site.

5. Preserve significant historic features (discussed under "Periods of Significance"), existing prior to 1961.

   Advantage: Would preserve the greatest amount of extant historic fabric; would avoid the issues of documentation needed to satisfy the standards for restoration that would be required to reconstruct with a minimum of conjecture; preservation would be consistent with the GMP and NPS policies; and would allow interpreting Spanish period features without destroying significant twentieth-century features.

   Disadvantage: "Preservation" could be considered as a "restoration" to a period; would be difficult to interpret easily; and would require a large amount of interpretive tools to insure that visitors understand the anachronistic setting with a minimum of confusion.

6. No Action.

   Advantage: Would be the easiest to implement, and would cost the least.

   Disadvantage: Deterioration would continue at an ever increasing rate; when work is eventually accomplished, the cost would exceed the cost of having done the work previously; historic fabric would be lost; this alternative would be inconsistent with the GMP and NPS policies.

RECOMMENDATIONS FOR GENERAL TREATMENT

Taking into consideration the nature of the cultural resources, their intended use and interpretive value, the size of the park staff, and the likelihood of future funding increases, this report recommends that Treatment Alternative no.5 be implemented. This option is close in intent to the direction outlined in the GMP and would maximize protection of all historic fabric. It is slightly different from the GMP because it excludes repairs by the U.S. Army and remnants of Fort Brooke from the category of historically significant fabric.

Management Issues

Over the course of the past five years, a number of preservation issues were raised as concerns by park staff. These concerns were formally recorded during discussions at the park and are summarized below. They range from very broad questions about general treatment of a resource to specific problems associated with a particular feature. Given a comprehensive approach to the treatment of the fortifications, most of these issues can now be resolved.

Issue: Remove later U.S. Army military facilities.

Remnants of Fort Brooke are by definition non-historic. Their removal should be approved provided (a) that no damage will occur to historic fabric as a result of demolition and (b) that removal will not require restoration of an undocumented feature from earlier periods.

Components of the World War II era harbor defense system are defined as historic structures and should be preserved. However, because they are of secondary significance by comparison with the Spanish II period features, these components may be considered for removal in the interest of interpretation or if it is discovered that they are adversely effecting the Spanish-built forts. As was outlined above, removal should only be considered if no damage will occur to historic fabric and if subsequent restoration is properly supported with historic documentation.

Issue: Preserve the lighthouse at el Morro.

Work supported by this HSR is currently underway.

Issue: Preserve the city walls and bastions.

Concur; see the section on specific treatments.

Issue: Repair the storm drainage system.

Work on the storm drainage system is important for preservation of the city walls and bastions. Additional research is needed to establish the origins and history of the system, but to the extent that it was built or repaired by the U.S. Army, it can be treated as a non-historic feature.

Excavations in an around the drainage system should always include an archeologist because of the potential for discovering additional information about the Spanish period.

Issue: Restore San Cristóbal.

This issue is inconsistent with the overall treatment strategy and the GMP.

Issue: Rehabilitate Quarters 209.

This issue is addressed by a separate HSR. Work is currently underway.

Issue: Preserve sentry boxes.

Very few of the Spanish-period sentry boxes have survived. Every effort should be made to preserve these distinctive features. The remaining sentry boxes are typically concrete replacements introduced by the U.S. Army. Technically, they are non-historic features but should be treated as if they were historic due to their prominence and character defining nature. See the section on specific treatments.

Issue: Repair the triangular and circular stairs.

This work has been completed according to the provisions of this HSR; see the section on specific treatments.

Issue: Repair and preserve the water collection system.

Concur; see the section on specific treatments.

Issue: Preserve metal hardware and related elements.

Concur; see the section on specific treatments.

Issue: Rehabilitate the electrical generating station.

This work applies to a non-historic feature. It has been cleared and implemented.

Issue: Rehabilitate the Civil Defense building.

The Civil Defense building is a part of the harbor defense system built during World War II and should be managed as a historic structure. However, as a structure with secondary significance, it would be appropriate to rehabilitate this facility in order to minimize changes to the Spanish-era structures. See the section on specific treatments.

Issue: Rehabilitate employee housing.

Employees are currently housed in historic structures outside the wall of San Cristóbal. Plans are also underway for expansion of housing into Quarters 209 (see issue above). These proposed actions are consistent with the overall strategy for treatment of the fortifications.

Issue: Stabilize the cisterns at el Morro.

Concur; see section on specific treatments.

Issue: Preserve the cisterns at el Morro.

Concur; see section on specific treatments.

Issues Related to Material Condition

During preparation of this report, a number of technical issues were added to the ones already identified by the park. Some of the issues overlapped, but the new issues were distinguished by a focus on materials and the forces causing their deterioration. This orientation is central to the comprehensive strategy recommended above and is essential for effective preservation treatment. The issues are outlined below as they were initially stated by the investigators. They are discussed in detail in the section on specific treatments.

-The effect of Portland-cement patches on historic masonry.

-Erosive action of sea water and wave action on historic walls.

-The effect of biological growth, both micro and macro, on historic masonry.

-Causes of mortar and stucco loss, the erosion of paved areas, and the implications of these changes.

-Deterioration of terracotta plaques.

-Deterioration of painted surfaces.

-Preservation of wood features such as doors, shutter, gates, frames, fragments of gun racks, etc.

-Deterioration of brick masonry.

-Deterioration of sandstone masonry.

-Oxidation of metal hardware, both historic and reproduction.

-Deterioration of historic graffiti and decorative paintings.

-Erosion of stair treads and nosings.

-Impact of vehicles on walls and other surfaces.

-Impact of natural disasters such as earthquakes and hurricanes.

-Effects of water infiltration, drainage and disposal.

-Effects of condensation created by air-conditioning on masonry walls and finishes.

RECOMMENDATIONS FOR SPECIFIC TREATMENTS

Issues and Recommendations

The following recommendations are considered to be the most important actions that can be taken at this time to help preserve the fortifications at San Juan. The recommendations responsd to issues raised by park staff as well as those identified later by the research team that wrote this HSR. A summary of these issues is outlined in the preceding section.

Although each of the recommendations addresses an important issue, they are not equally well developed in scope or detail. The purpose of this HSR was very narrow; to confirm the historical development of the San Juan fortifications through fabric analysis and examination of primary documents. The result of this effort has been considerable, but more questions were raised than were answered by the investigation. A few of the problems that have been raised are impossible to answer given the existing information base. However, there is plenty of information available to address the most critical issues. More specialized investigation can be pursued to answer remaining questions.

Three additional points need to be made at this juncture.

First: The recommendations are for the most part written in broad terms. In order for these recommendations to be implemented, some decisions must be made about the physical sequencing of work. In other words, someone will need to decide on a place to start and the order in which other areas will be treated.

Second: Sequencing should be based in part on the condition and significance of individual features or sets of features.

Third: The detailed technical information needed for preservation treatment is, for the most part, not addressed in this HSR. It should be developed as work procedures, schedules, instructions, and so forth, within the framework of Maintenance Management.

Priority Setting Based on Significance and Condition

Setting of priorities for preservation treatment is a practical necessity with significant implications for the objectives of the program. Priorities will reflect preservation variables such as the relative significance of the feature and its condition. Broadly speaking, greater attention

should be given to distinctive features before common ones. Structurally damaged elements should be secured before work begins on finishes, and causes of deterioration should be corrected before repairing the consequences. Priorities will also reflect the quantity of available funds, the number and skills of available craftsmen, and the degree to which support documents are available to guide the work.

To help set priorities for treatment, three terms will be used as indications of preservation concern. The terms are "urgent", "necessary", and "desirable." They are defined as follows:

Urgent: Essential, required to correct structural deficiencies; and essential in order to stabilize distinctive architectural features, an example of skilled workmanship, or character-defining elements.

Necessary: Essential, required to ensure the benefits of past preservation efforts and to maintain acceptable conditions; essential, required to defer major anticipated effects by known threats.

Desirable: Repair deteriorated (non-structural) conditions; restoration of historic feature; and removal of non-historic features.

SPECIFIC RECOMMENDATIONS

In order to accomplish the stated objective of preserving the significant historic structures at San Juan NHS, twenty specific actions are needed. These recommendations are organized in order of priority according to preservation concerns. The twenty recommendations are listed below. A detailed discussion of each recommendation follows.

1. Repair el Morro Lighthouse
2. Stucco Exterior of Masonry Walls
3. Stucco and Repair Embrasures
4. Repair Paved Surfaces
5. Preserve Decorative Finishes and Graffiti
6. Repair Interior Plaster
7. Repair Drainage Lines within Fortifications
8. Preserve and Repair Sentry Boxes
9. Preserve Wood Elements
10. Preserve Metal Elements
11. Preserve Terracotta
12. Repair and Maintain Historic Stairs
13. Repair and Maintain Tunnels
14. Repair and Maintain Historic Concrete
15. Develop Cyclic Maintenance Program
16. Mitigate the Effects of Air-conditioning
17. Monitor the Effects of Wave Action and Sea Water on Historic Walls
18. Develop Emergency Management Plan for Historic Structures
19. Determine Appropriate Uses for All Historic Structures
20. Preserve the Cultural Landscape and Viewsheds of el Morro

Recommendation 1 - Repair el Morro Lighthouse

Affected Features: The lighthouse is a three story cylinder. Major features include corbelled brick walls, the light, a lantern and metal stairs. The parapet around the lantern is decorated with crenelations and miniature sentry boxes.

Materials Involved: Fired brick, portland cement mortar, paint, glass, cast iron, bronze or brass, and rolled steel.

Condition: The exterior walls of the lighthouse are badly eroded and cracked.

Causes of deterioration: Two factors have been central to the deterioration of the lighthouse. First, the walls were not kept painted. This led to absorption of water by the brick. Since the brick was more porous than the surrounding cement mortar, water tended to evaporate from the brick rather than at the joints. Resultant salt crystallization pulverized the brick and allowed even greater water penetration. Second, as a result of increased moisture content in the brick, metal components tended to rust. This phenomenon is known as "rust jacking." Expansion of the metal through rust exfoliation fractured adjacent brick and created new avenues for water infiltration.

Implications: If the walls are not repaired and a weather-resistant envelope reestablished, deterioration of the lighthouse will accelerate to the point of structural collapse.

Priority: Urgent.

Action: Replace or repair deteriorated brick, clean and fill masonry cracks, remove rust from steel and iron components, and repaint. Repair deteriorated features of the lantern including broken lights and the dome. Ensure that all exterior surfaces are weather resistant.

Notes on Masonry Repair: Loose brick or brick deteriorated more than 2 inches from the face should be removed. Replacement brick should match its corresponding unit in size, finish, and configuration. These qualities are important because at least two sizes of brick were used in construction of the lighthouse and not all units are flat. Color is not significant because the masonry is to be painted. The replacement brick may also differ from the original by virtue of greater strength and less porosity.

Cement mortar surrounding deteriorated masonry should be taken out at the same time as the brick. Joints can be

raked with a low-impact pneumatic tool but should be closely monitored to prevent damage to intact historic fabric. A low porosity preservation mortar should be used to set the new units.

Brick with less than 1 inch of deterioration should be cleaned of all loose and flaking material and coated with a cementitious material. This material should be similar to the terracotta and brick restoration mortar manufactured by Jahn. It should be applied according to the manufacturer's instructions. Cement mortar around these shallow cavities should not be removed as in the case of brick replacement.

When all of the mortar joints and cementitious fill have set and cured, the exposed surfaces of the wall should receive three coats of exterior latex paint such as Thorosheen by Thoroseal.

Notes on Repair of Structural Metal: The ceiling of the lighthouse is a series of shallow concrete vaults cast in place between steel I-beams. The bottom of the I-beams should be completely exposed by removal of concrete immediately above the flange. This area should then be lightly scraped and saturated with a tannic acid solution to consolidate the remaining exfoliated material. The solution should consist of 2 parts tannic acid, 4.3 parts distilled water, and 0.7 parts denatured alcohol. Exposed portions of the beams should then be primed and painted with a semi-gloss interior acrylic latex. A cementitious mortar should then be used to repair the concrete cut-out above the flange.

At the exterior wall locations, the I-beam is supported on a square iron plate. Where this plate has not rusted badly it can be scraped, treated with tannic acid solution, painted, and reused. Badly deteriorated plates should be replaced with galvanized steel cut to the original dimensions. The pads should be set in a bed of cementitious, non-shrinking, non-metallic grout. Masonry around the pads, including any cracks caused by rust jacking, should be repaired as outlined above.

Notes on Repair of the Lantern: The lower half of the ball vent from the top of the lantern dome is badly deteriorated. Rather than replace it with cast iron, it is recommended that a non-rusting material be used. This hemisphere should then be fitted with a stainless steel mesh to prevent access by birds, bats, and insects. The ball should then be cleaned of flaking material, primed with a zinc chromate primer and finished with two coats of black, high-gloss exterior acrylic latex.

The ball attachment rod should be modified by the addition of a threaded rod to which the weather vane can be connected with a threaded coupler. This will center the ball over the vent pipe while still allowing for future removal of the ball and the vane.

The weather vane should be disassembled, cleaned and repaired. The ball bearing mount should be replaced with copper assembly of appropriate size and configuration. Cleaning should consist of a mild, neutral ph wash and rinse. No sealers or coatings should be used.

The cap rail and standards should be replicated in mild steel to match the original in configuration, size and placement. It should be joined by welding and ground smooth.

The original door frame of the Light Room was a single unit of cast iron. It is badly rusted and broken in several pieces. Due to the high cost of recasting, the frame should be replaced with a new assembly fabricated from cold-rolled mild steel. The configuration of the frame should be retained in order to allow installation into the surrounding masonry wall. As with all metal components, the frame should be cleaned, primed and painted prior to installation.

A new metal door should be fabricated to replace the original cast iron unit. It should be made of mild steel and finished like the door frame.

Deteriorated deck plates should be recast to match the originals in size, material, and detail. Deck mounts should be repaired by welding steel plates beneath the mounting brackets. These plates will accept new stainless steel anchor bolts as part of the reassembly. They should be set in mortar after the final repairs are completed. Joints between plates should be filled with an acrylic caulk. All metal components should be primed and painted.

The lantern glazing system should be repaired by replacement of broken glass, missing mullion pieces, and improperly sized mullion bolts.

The lantern dome should be scraped, sanded and primed with a zinc chromate primer. Areas of severe exfoliation should be cut out with a torch and infilled with metal patches welded in place and ground smooth. The cornice should be scraped, sanded and primed with a zinc chromate primer. The severely deteriorated 1 inch banded drip edge should be cut away and replaced with a new matching piece in a manner that allows air to vent into the dome. The grate located at the first floor of the lantern venting stack should be re-

installed and secured in the open position to insure positive venting of the lighthouse interior.

Recommendation 2 - Stucco Exterior of Masonry Walls

Affected Features: All masonry walls, especially city walls and exterior walls of el Morro and San Cristóbal. Special attention should be paid to color, texture and tooling.

Materials Involved: Primary materials include stone, brick, mortar and historic stucco. Other materials that might be effected by the treatment include wood, concrete, terra cotta, bronze, paint, tile, glass, sod and plants.

Condition: Much of the exterior stucco is missing or eroded. Remaining portions are generally in good condition.

Causes of deterioration: Major causes of deterioration include water, biological growth, and lack of cyclic maintenance. Additional causes include impact by vehicles or machinery, human contact, and wave action.

Implications: Infiltration of water through exposed masonry is the major threat to long term stability of the fortifications. Increased moisture content in the walls is a contributing factor in deterioration of interior plaster and loss of decorative finishes.

Priority: Necessary.

Action: Reapply stucco where missing or eroded to recreate a smooth finish.

Technical Discussion: The first step in stucco repair is to clean the walls biological growth with a water-soluble treatment such as the application of a gentle detergent with an NPS approved biocide added to the solution. Solution may be applied with pressure water spraying equipment. Loose and deteriorated material should be removed, (if non-decorative), and portland cement patches that are causing deterioration should be removed to a depth of at least two inches. The cement patches should be removed because they are contributing to the breakdown of the adjacent masonry.

Because the walls are assumed to contain significant amounts of water, stucco application should be done in stages beginning at the tops of the merlons. The remainder of the surface should be done in horizontal bands 15 to 20 feet wide, starting from the top. This will allow water to move down the walls and evaporate at the lower levels. A break

of six months to a year should be allowed between completion of one band and initiation of the next one down.

New stucco should match the historic stucco in color, texture and tooling. It should be composed of lime, sand and white portland cement. Treatment of non-defensive interior wall surfaces should be started after the upper level of the exterior fortified walls have been completed. The upper level walls should precede those on the lower levels. Once the stucco has been applied, it should be maintained by the regular application of a lime wash.

Much as painting wood siding is the traditional method of preserving a wood structure, stuccoing the walls at San Juan is the historic technique for masonry preservation. However, it should be noted that this process will visually affect the appearance of the fortification and create the impression of "newness." This is objectionable to those who prefer that the walls look old. Unfortunately, the look of antiquity is actually a sign of deterioration that will eventually lead to destruction of the walls. Stuccoing the walls has, in fact, not been done at San Juan for more than a century and is badly needed.

Recommendation 3 - Stucco and Repair Embrasures

Affected Features: All merlons and banquettes.

Materials Involved: Primary materials include stone, brick, hormigón, and historic stucco. Other materials that might be effected by the treatment include the rubble fill of the walls.

Condition: Much of the stucco and hormigón covering the brick and stone of the merlons and banquettes is missing or severely eroded. Remaining portions are generally in fair condition.

Causes of deterioration: The major cause of deterioration is natural weathering (i.e. hard rain, wind, and wind driven particles). Additional causes include the former use of incompatible patching materials such as portland cement, lack of cyclic maintenance, and pedestrian traffic.

Implications: Erosion through weathering leads to a loss of stucco and hormigón. As a result, top surfaces of merlons no longer prevent water from infiltrating and there is a possible slumping of interior fill.

Priority: Necessary/Urgent.

Action: Reapply stucco where missing or eroded to recreate a smooth finish. Replace all deteriorated edging brick on the merlons and banquettes as well as the deteriorated 1930s brick along reconstructed banquettes.

Technical Discussion: Preparation for reapplication of stucco should include cutting out unsound (loose and deteriorated) material with hand held tools (hammers and chisels), keying surface to receive new patch or stucco application, and rinsing surface with low pressure water wash to remove debris. Portland cement patches contributing to the breakdown of adjacent masonry should be removed to a depth of at least two inches.

New stucco applied to surfaces should match the historic stucco in color, texture and tooling. A preservation mortar should be developed consisting of lime, sand and white portland cement. The surface should be floated.

Eroded brick edging on banquettes and merlons should be replaced with new brick matching the original in color, size, and texture. A preservation mortar consisting of 1 part white portland cement, 2 parts lime, and 7-9 parts sand should be used with adjustments in color and texture to match historic mortar. New brick to be then covered with stucco according to new stucco mix described above. Merlons faced with cast composite stone should likewise be stuccoed in accordance with above stucco recommendations. Eroded elements should either be patched or filled in with new stucco.

Decorative surfaces (e.g., faux ashlar, ship drawings, and historic graffiti) such as those found on the embrasures of el Abanico are discussed in Recommendation 5.

Recommendation 4 - Repair Paved Surfaces

Affected Features: Terrepleins, gun emplacements, ramps, and gutters. Elements included within these features are portland cement patches and contemporary hormigón repairs.

Involved Materials: Primary materials include stucco pargetting with brick dust, hormigón, and historic mortar.

Condition: Surfaces are generally in good condition with areas of severe erosion.

Causes of deterioration: Major causes of deterioration are water penetration, inadequate drainage, and natural weathering. Additional causes include former vehicular impact, pedestrian traffic, and the oxidation of iron gun

emplacement tracks. It is likely too, that the use of portland cement mortar for repairs over the years and the lack of cyclic maintenance have exacerbated deteriorated conditions.

Implications: All major causes of deterioration result in the loss of a protective outer layer and the infiltration of water through exposed masonry. Infiltration of water is thus a threat to the stability of the infrastructure beneath the paved surfaces.

Priority: Necessary.

Action: Replace in kind all worn, missing and eroded stucco pargetting, hormigón and mortar. After repairs, curtail all vehicular traffic except for emergency purposes. Repoint open brick joints. Reline gutters. Remove rust from iron gun emplacement tracks and apply a protective finish. Replace eroded brick at gun emplacements. Reconstruct gun emplacements where necessary.

Technical Discussion: A preservation mortar mix should be developed to replace deteriorated hormigón and stucco pargetting that will match the original in overall texture and color. The mortar should have a binder of 1 part white portland cement and 1 part lime; the aggregate should be a mixture of sand and brick dust, and gravel size brick chunks where appropriate. The exact proportions should be site tested to match adjacent historic material. In addition, appropriate porosity is of primary importance in developing preservation mortars. The surface should be floated and coated with a yellow coating developed for the walls (or a derivation of this coating, altered to accommodate pedestrian traffic).

Patches of portland cement that are causing deterioration of adjacent original hormigón should be removed in whole or part depending on size and degree of deterioration. If the bond between the cement patch and the hormigón has deteriorated, as evidenced by an open space between the two, the patch should be partially removed around the edges and the resulting void filled with the new preservation hormigón mix described above.

Gutters and drainage systems should be cleaned and subsequently kept free of debris and obstructions. Open brick joints should be cleaned out and repointed with a preservation mortar consisting of 1 part white portland cement, 1 part lime, and 5-6 parts sand. Adjustments in color and texture should be developed by the masons on site to match the historic mortar if exposed. The mix should be

in sympathy with the historic material and be of the appropriate porosity.

Gutters should be relined with a thin layer of hormigón according to the mix described above excepting any brick chunks in the aggregate. The hormigón should be floated and coated as specified above.

Rust should be removed from the iron gun emplacement tracks and then primed and finished with an appropriate recommended protective coating. (See Recommendation no.1.)

Eroded brick associated with the gun emplacements should be replaced. Replacement brick should match the original brick in color, size, and texture. They should be harder than the original brick because the original was much too soft to withstand the harsh weathering patterns of the locale. A preservation mortar similar to that described above for repointing open brick joints should be used in replacing eroded brick.

Gun emplacements should be reconstructed where necessary to match originals in appearance. Materials used in the reconstruction should match original materials in texture, color, and style. Photographs and drawings from the San Juan NHS Archives should be used to determine original configurations.

Holes in the terreplein associated with former wooden elements of gun emplacements (situated at the center and sides of tracks) should either be filled with replacements for missing wooden elements (if the original appearance is known) or filled with hormigón, perhaps of a slightly different color or texture, to mark the site of the missing wooden elements.

Recommendation 5 - Preserve Decorative Finishes and Graffiti

Affected Features: Decorative finishes include the yellow ocher colored finish found on stuccoed surfaces, the painted brick-red highlights also found on stucco surfaces, and red or yellow faux ashlar work found primarily on merlons, salient angles, ramps and gates. Wall paintings are found in the cisterns of San Cristóbal. Drawings of ships are found on the walls at Santa Elena and Santa Barbara Batteries (el Morro) and in the tunnels at San Cristóbal. Scribed drawings of ships, geometric shapes, and historic graffiti are found on the walls of el Abanico and Santo Domingo Bastion. In addition, geometric drawings are extant on the walls of the tower and the triangular stair of el Morro.

Materials: Primary materials include paint, scribed lines and stucco.

Condition: Severely eroded to fair. Decorative paintings are in very fragile condition with widespread surface flaking.

Causes of deterioration: Major causes of deterioration are natural weathering and biological growth on exterior finishes and water infiltration and biological growth on interior finishes and paintings. Additional causes include the lack of cyclic maintenance and human contact (touching, etc.).

Implications: Weathering will eventually erase many of the exterior finishes by simple wear and tear. Biological growth and water infiltration leads to efflorescence and calcium carbonate deposits on finished surfaces causing separation from the stucco surface and flaking of the paint or pigment. The crumbling of the substrate will eventually cause the disappearance of finishes.

Priority: Necessary.

Action: The unique drawings in the tower and in the triangular stair of el Morro, and the tunnels and cisterns in San Cristóbal should be protected from physical damage. Resurfacing exterior walls and terrepleins should retard the amount of water infiltrating the masonry in these areas. Due to the fragile nature of these drawings, a conditions report and recommendations for preservation should be made by a painting conservator.

The drawings of ships executed on the merlons of Austria Bastion, Santa Elena Bastion, and Santa Barbara Battery are faint. They should not be covered over with stucco. It may be desirable to cover them with a clear protective coating if recommended by a painting conservator. If stuccoing over some of these is necessary to prevent water infiltration, it may be necessary to use an isolating layer (a clear coating over the drawing so the stucco doesn't actually touch the drawing). This would also be studied by a conservator before implementation.

The decorative wall paintings (some of which are thought to have been painted by Campeche, one of Puerto Rico's most renowned artists), should be evaluated for conditions, materials and attribution by a professional painting conservator. Conservator should make recommendations for their stabilization. Preservation treatments should be implemented soon to insure that these important paintings do not deteriorate further. It may be desirable to open the

cisterns to visitation and to provide interpretation for the paintings therein.

Deteriorated faux masonry finishes should be replaced in kind. Preservation mixes for white and brick-dust stucco should be developed and used where appropriate. The exact proportions should be site tested to match original material in color, texture, and porosity.

Recommendation 6 - Repair Interior Plaster

Features: All interior surfaces of buildings comprised of painted plaster, stone and brick as well as the undersides of vaults and interior of the cisterns at el Morro and San Cristóbal.

Involved Materials: Primary materials include painted plaster, stone and brick. Other materials that might be effected by the treatment include flooring and any wooden elements (vigas, doors, window surrounds, etc.), concrete, tile, glass, and bronze.

Condition: Generally in sound condition, but demonstrating cracking, mold growth, surface accretions and open joints.

Causes of deterioration: Major causes of deterioration include increased humidity caused by the installation of air-conditioning units and deferred maintenance. Secondary causes include water infiltration and the choice of original material and stucco mixes. Major causes of deterioriation in the cisterns are water penetration, use of portland cement mortar, and deferred maintenance.

Implications: Increased humidity leads to biological growth and increased water content within the walls as well as the loss of decorative finishes. Water infiltration leads to a loss of protective outer layers and increased deterioration within masonry walls.

Priority: Necessary to urgent.

Action: Remove and replace all unsound plaster.

Technical Discussion: Remove unsound plaster with hand held tools (hammers and chisels), key area to receive patch or new coating, and rinse with water to remove dust/debris. A preservation plaster mix should be developed that is sympathetic to the adjacent historic materials. Reapply new plaster where necessary.

Interior plaster surfaces with mold should be washed with a solution selected for its ability to remove and inhibit further mold growth.

Cracking resulting from structural problems should be further investigated, monitored and treated according to a professional recommendation.

All open joints should be repointed with a preservation mortar comprised generally of 1 part white portland cement, 2 parts lime, and 7-9 parts sand. Specific proportions should be site tested to match historic mortar in color, texture and porosity.

Horizontal surfaces such as pavements above vaults that allow moisture infiltration, should be repaired or made sound by cutting out unsound areas and repaving. Moisture shedding systems should be examined (see Recommendation no.7) and if necessary redesigned to inhibit leakage.

Consideration should be given to removal of air-conditioning units. See recommendation no.16.

Reworking the interior plaster surfaces will necessarily impact interior decorative finishes and wall paintings. See Recommendation no.5 for protection and treatment recommendations for these features.

Recommendation 7 - Identify and Examine Water Drainage System

Affected Features: Pipes, drains, conduits and scuppers within the fortifications.

Materials Involved: Materials are largely unknown but it is suspected that cut sandstone, brick, hormigón, stucco, mortar, clay and cast iron were used in the system.

Condition: Unknown.

Causes of deterioration: Water infiltration (standing water), biological growth, cracking, and blockage.

Priority: Necessary.

Action: Locate, identify, and examine all below surface drainage lines. Map all drainage lines. Repair all drainage lines where necessary.

Technical Discussion: The drainage lines within the fortifications present a separate technical problem than either the depressed gutters on the paved surface or the

subterranean cisterns at el Morro and San Cristóbal. Their location and function is largely unknown and yet they are an important feature of the site and could be a major cause of deterioration within the masonry structure. The first step in preserving the drainage system is largely a research problem. Once conduits are located, tracked, and examined, the existing conditions, involved materials, and nature of needed repairs can be assessed.

Recommendation 8 - Preserve and Repair Sentry Boxes

Affected Features: Sentry boxes throughout el Morro, San Cristóbal, and the City Walls.

Materials Involved: Brick, cast-concrete blocks, cut sandstone, and cast-concrete finials.

Condition: Good to poor.

Causes of deterioration: Primary causes of deterioration are high moisture content, water infiltration, wave action and salt corrosion due to proximity to the sea. (Efflorescence and calcium deposits leaching from the masonry are apparent.) Natural weathering is also a major cause of deterioration due to the largely unprotected position of the boxes. Other causes of deterioration include water infiltration, visitor traffic, and lightning strikes.

Implications: Infilitration of water through exposed masonry is the major threat to long term stability of the sentry boxes. Increased moistrue content in the walls could lead to a complete failure of structural integrity.

Priority: Desirable.

Action: Replace in-kind. The historic brick and stucco sentry boxes should be inspected and treated on a case-by-case basis. Some may require replacing deteriorated brick with new brick to match. Replacement mortar should be based on a preservation mix consisting of 1 part white portland cement, 1 part lime, and 5-6 parts sand with exact proportions determined on site to match color, texture, and porosity to historic mortar. Mortar should then be covered with new stucco as specified in Recommendation no.3. Other sentry boxes may require casting new iron elements and/or stucco covering. It should be noted again, that not all sentry boxes are historic but that it is desirable to maintain all boxes to the same standards because of their character defining nature.

Recommendation 9 - Preserve Wood Elements

Affected Features: Wooden elements including doors, window shutters, door and shutter enframements, gates and enframements, and the "gun rack" at el Morro.

Materials Involved: Wood, metal, glass.

Condition: Moderate to poor.

Causes of deterioration: Natural weathering, lack of protective coatings, and environmental conditions (e.g., high moisture and salt corrosion).

Priority: Necessary.

Action: Doors, window shutters, door and shutter enframements, gates and enframements, and the "gun rack" should be painted after proper preparation with a color matching one of the historic finishes identified in the paint analysis contained in Appendix I. Original paint samples are located at the Building Conservation Branch, NPS, NARO, Boston, MA.

Extant paint in good condition should be painted over. Extant paint that has failed (i.e. badly alligatored) should be removed before repainting). Ausubo features such as stair nosings and handrails should be left unpainted.

A cautionary note for consideration when choosing new paint finishes: It is difficult to distinguish wooden elements that have been replaced over time from those that are original. The painted finishes on wooden elements identified through analysis therefore, are representative only of wooden elements as they exist today at the fortifications.

Recommendation 10 - Preserve Metal Elements

Affected Features: Iron gates and wrought-iron hardware, etc.

Materials Involved: Wrought-iron and steel. Does not include brass, bronze, or copper.

Condition: Good to severely rusted.

Causes of deterioration: Environmental conditions (e.g., high moisture and salt corrosion), natural weathering, lack of protective coating, and deferred maintenance.

Priority: Necessary.

Action: De-rust, repair and stabilize iron and steel (not brass, bronze, and copper) elements.

Technical Discussion: Metal should be lightly scraped and saturated with a tannic acid solution to consolidate the remaining exfoliated material. The solution should consist of 2 parts tannic acid, 4.3 parts distilled water, and 0.7 parts denatured alcohol. Metal should then be primed with a zinc chromate primer and painted with a semi-gloss interior acrylic latex. Severely exfoliated metal should be cut out with a torch and infilled with metal patches welded in place and ground smooth.

Recommendation 11 - Preserve Terracotta

Affected Features: Plaques fixed to the walls at el Morro and near the Gate of San Juan.

Materials Involved: Burnt or fired clay.

Condition: Good to deteriorated with areas moderately eroded.

Causes of deterioration: Primary causes of deterioration are the moist environment, the fragile nature of the material, and efflorescence.

Priority: Desirable.

Action: Protect the plaques against further deterioration, monitor, and make appropriate recommendation for treatment.

Recommendation 12 - Repair and Maintain Historic Stairs

Affected Features: Masonry stairs including triangular stairs, circular stairs, and straight stairs, both exterior and interior.

Material Involved: Brick, stone, mortar, stucco or hormigón, and wood.

Condition: Severely eroded to good.

Causes of deterioration: Natural weathering, excessive pedestrian traffic, loss of surface stucco or hormigón, and the use of poor quality materials.

Priority: Necessary.

Action: Brick and pavers that have eroded should be replaced with new material matching the original in color, size, and texture. New brick may need to be harder than the original brick. Units should be set with a preservation mortar matching the original in overall color, texture, and joint profile such as that recommended for the sentry boxes in Recommendation 8.

Surface stucco or hormigón should be replaced where it has eroded. Brick should be repaired first, and then recovered with stucco or hormigón. (See recommendation no.3.) Eroded or rotted wooden elements (railings and nosings) should be replaced with ausubo. No coatings or preservatives are recommended.

Recommendation 13 - Repair and Maintain Tunnels

Affected Features: Six tunnels located at San Cristóbal and two at el Morro.

Materials Involved: Stone, brick, mortar and stucco.

Condition: Generally stable condition, with leaching, biological growth, open joints, cracking, and patching.

Causes of deterioration: Major causes of deterioration are moisture penetration, biological growth and lack of adequate ventilation. Additional causes of deterioration include the installation of modern portland cement patches and installation of modern lighting systems.

Priority: Necessary to urgent.

Action: Point all open joints with preservation mortar and match color, texture, and porosity on site. (See Recommendation no.3 for basic proportions.)

Remove deteriorated stucco and repair in accordance with previously described stucco repairs. (See Recommendation no.6)

Portland cement patches should be removed or repaired in accordance with previous recommendations no. 2 and no.4.

Examine ventilation of the tunnels and investigate the possibility of improving air circulation, etc.

Recommendation 14 - Repair and Maintain Historic Concrete

Affected Features: Concrete structures associated with World War II Harbor Defense System.

Materials Involved: Poured-in-place concrete and reinforced concrete.

Condition: Moderate to good.

Causes of deterioration: Natural weathering, water infiltration, and rusting of metal reinforcing rods.

Implications: Failure to repair or maintain these features will result in their eventual deterioration and structural collapse. Loss of some concrete features may adversely effect portions of the fortifications built during the Spanish periods.

Priority: Desirable.

Action: A long-term preservation strategy is needed for these features. Because of their history and unique nature they should be the collective subject of a new Historic Structure Report (HSR). The HSR should focus on treatments needed for preservation and should be accompanied by a cyclic maintenance program (see Recommendation no.15)

Recommendation 15 - Develop Cyclic Maintenance Program

The majority of work needed to preserve the San Juan fortifications involves repair and maintenance of historic materials. Specific guidance for this work should be prepared in a manner consistent with the Inventory and Condition Assessment Program (ICAP). This program is compatible with Maintenance Management (MM) and provides a link between cultural resource management and MM.

The cyclic maintenance program contained within ICAP should include procedures and schedules for both inspection and work activities. The program could be developed incrementally, beginning with the most urgent and immediate tasks. Each work procedure should specify in detail the materials and techniques necessary for high quality accomplishment of a given treatment.

Recommendation 16 - Mitigate the Effect of Air-conditioning

Affected Features: Exterior walls at the North Casemate and Officers' Quarters of San Cristóbal, any air-conditioned

rooms including museum spaces in el Morro and the study collection in the Troops' Quarters at San Cristóbal.

Materials Involved: Stucco and masonry.

Condition: Areas under the air conditioning units are badly deteriorated. Walls within air-conditioned spaces typically contain high amounts of moisture due to condensation and are in a state of imminent deterioration.

Causes of deterioration: Water condensation from the air conditioning units is allowed to drain onto the walls. The water causes a breakdown of stucco by mechanical action (washing over the material) as well as by absorption. Evaporation of the absorbed water results in salt crystallization which, in turn, breaks down the historic material. Loss of stucco, combined with increased moisture in the walls, also creates a suitable environment for growth of mold, algae and herbaceous plants--thus further destroying wall surfaces and threatening the structural integrity of the walls themselves.

Walls within air conditioned spaces are also subject to increased moisture content due to condensation. This condition occurs when moisture rich air comes into contact with cool wall surfaces. High relative humidity is associated with unconditioned (outside) air and conditioned air that has not been through a dehumidifier.

Implications: Without correction and repair the walls under the air conditioning units will continue to deteriorate at an increasing rate. Walls in conditioned spaces may lose their plaster coatings and certain decorative finishes could be damaged.

Priority: Necessary.

Action: Patch and reapply stucco after cleaning walls of vegetation and unsound stucco. Investigate the possibility of installing a balanced climate control system with humidity controls in place of the individual units. Assess the impact of the proposal and compare with the alternatives of no action (continued use of individual units) and no conditioning. Implement the least destructive alternative given the uses assigned to a given space (see Recommendation no.19).

In addition to this specific action, all spaces that are air conditioned should be closely monitored in terms of temperature, humidity, and breakdown of historic materials. In conjunction with interpretive and curatorial staff, an

optimum balance should sought in terms of object conservation and structural preservation.

Recommendation 17 - Monitor the Effects of Wave Action and Sea Water on Historic Walls

The fortifications of San Juan NHS are surrounded on three sides by water. Responsibility for control of erosion due to wave action and sea spray is with the Corps of Engineers. Extensive repairs of bedrock underpinning the city walls and fortifications have been undertaken by the Corps over the past thirty years. So too, the Corps has created breakwaters and other devices to limit deterioration of the cliffs and their narrow beaches.

Periodic inspection of the coastline should be continued with particular attention to older repairs and areas of rapid deterioration. Recommendations for additional work should be coordinated with the Corps and funding secured in order to minimize large scale damage to the walls by undercutting of their foundations.

Recommendation 18 - Develop Emergency Management Plan for Historic Structures

The fortifications at San Juan NHS have been threatened by a number of destructive natural events in the course of their existence. The most recent was Hurricane Hugo in September, 1989, which caused a great deal of damage to the gates of the two forts. Other potential threats include earthquakes, rise of sea level, air pollution, and fire. Consideration might also be given to potential human threats such as riot and police actions.

A systematic study is needed to evaluate the possibility of these threats occurring, identifying likely effects, and outlining actions to minimize damage both before and after the event. The plan should be integrated with other emergency management plans of the park and the Commonwealth of Puerto Rico.

Recommendation 19 - Determine Appropriate Uses for All Historic Structures

A comprehensive review is needed of all uses, current and projected, within the fortifications and adjacent to the city walls. All NPS owned or administered properties should be included in this analysis, especially the Civil Defense Headquarters, Magazine, and Quarters Number 208 and 209.

This review should consider the implications of information contained within this HSR, especially the significance and condition of particular features.

Uses should be evaluated in terms of both program concerns and effects on historic material. Effects should include direct wear, functional requirements such as accessibility, safety, energy efficiency, space relationships, electrical power, water lines, furniture, and air conditioning.

Recommendation 20 - Preserve the Cultural Landscape and Historic Views of el Morro

The open spaces adjacent to el Morro and San Cristóbal were an integral aspect of these fortifications and are unique features worthy of preservation. The period of significance for these areas is the same as for the rest of the complex. In other words, the focus should be on maintenance of the landscape as it existed during the Spanish periods.

Research to date has focused on the space in front of el Morro (the Esplanade). Additional research is needed for the outworks at San Cristóbal and the areas adjacent to the city walls. Emphasis should be placed on determining the particular significance of the landscape, identification of significant features including vistas, evaluation of condition, and analysis of causes contributing to landscape deterioration. Once this investigation has been completed a comprehensive program for preservation should be developed and implemented.

GLOSSARY

GLOSSARY

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In addition, several of the report's authors provided verbal definitions. E. Blaine Cliver (EBC), Judy Jacob (JJ), Joan Berkowitz (JB) and Richard Crisson (RC) are cited below. The number of the source as listed here, follows each entry.

Argamasa: Mortar. (6)

Argamasar: To make mortar; to cement with mortar. (6)

Ausubo: A native hardwood of Puerto Rico used in the San Juan fortifications. Translates as "iron wood." (RC)

Banquette: Footstand for infantry behind a parapet. (4)

en Barbette: Raised platform from which guns can fire over a parapet. (4)

Barro: Clay, mud, daub. (6)

Bastion: A mass of earth, faced with sods, brick, or stones, standing out from a rampart, of which it is a principal part. A bastion consists of two flanks, each commanding and defending the adjacent curtain, or that portion of the wall extending from one bastion to another, and two faces making with each other an acute angle called the salient angle, and commanding the outworks and ground before the fortification. (4)

Batter: The inward inclination of a wall from the base. (4)

Bombproof: Building or a part of the defenses constructed to withstand cannon balls or shells. (4)

Cal: Lime. (6)

Cal y canto: Cut stone and mortar construction. (6)

Cantera: Stone quarry. (6)

Cantería: Quarried stone, cut stone; the art of cutting stone; building mad of squared stone, unit of squared stone. (6)

Caponier: Sheltered passage across the ditch leading to outworks and sometimes providing additional flanking fire for the ditch. (4)

capuchinos: A term used occasionally for hinges with a conical socket and pintle arrangement. So named for its resemblance to the hoods worn by Capuchine monks. (JJ)

Casemate: Vaulted chambers in the ramparts used as barracks or gun positions. (4)

Cavalier: A high work, built on a bastion or a curtain. (4)

Cortadura: Parapet with embrasures and merlons. (3)

Covered Way: Broad space on top of the counterscarp protected by a parapet from enemy fire. (4)

Counterfort: Buttresses built behind scarp walls in order to strengthen them. (4)

Countermine: A mine or tunnel dug by the defenders of a fortress to intercept and destroy a tunnel made by the besiegers. (4)

Counterscarp: Outer wall of a ditch. (4)

Curtain: Main wall of a defensive work; it is reinforced by bastions or towers placed at a distance from the main defenses, defending the approaches without supporting fire from the main fortification. (4)

Echaugette: A stone sentry box cantilevered from the angle of a bastion. (4)

Embrasure: Opening cut in a parapet, usually wider at the rear than at the front, through which a gun can be fired. (4)

Enfilade: Gunfire directed along the length of an enemy battle line. (9)

Enlucido: Plaster. (6)

Fraise: Palisades placed in a horizontal or nearly horizontal position. Of wood or iron, they are bound together by two ribands and buried in the ground. (10)

Gabelet: A small ornamental gable. (8)

Glacis: Long gentle slope beyond the ditch which is kept clear of all obstacles. (4)

Hormigón: Concrete (contemporary meaning); poured cementitious paving material (historical use). (6)

Hornwork: An important outwork consisting of a curtain wall flanked by two demi-bastions. (4)

Ladrillo: Brick, brick masonry. (6)

Mampostería: Rubble masonry. (JJ)

Merlon: Solid part of a parapet, between two crenelles or embrasures. (4)

Parapet: Breastwork on top of ramparts, thick enough to cover troops behind it. (4)

Pie: Historical spanish measuring unit. 1 pie = 11.2 inches. (EBC)

Piedra: Masonry construction; stone. (6)

Pomerium: Open space between the walls of a fortress or town and the outermost houses. (4)

Rampart: Fortified embankment topped by a parapet. (4)

Revellín: Triangular outwork with or without flanks, usually placed in the ditch in front of a curtain. (4)

Redoubt: Small work in a bastion or ravelin, or one placed beyond the glacis but within range of muskets on the covered way. (4)

Relleno: Fill material in wall (generic term, not found in historical sources).

Ripio: Tabby (probably oyster shell tabby). (6)

Sacado a plano: Planed surface (archaic). (JJ)

Salient angle: Outward point of a bastion or other projecting work. (4)

Scarp: Interior wall of a ditch or moat. (4)

Secco: The art of painting on dry plaster. (8)

Sillería: Quarried stone; ashlar (archaic). (JJ)

Tambour: A defensive work formed of palisades, intended to defend a road, gate, or other entrance. (1)

Tapia(ria): Tamped earth, rammed earth (either lime or earth). (6)

Tejas: Clay tile. (6)

Traverse: Barriers constructed on places like the covered way to protect troops and guns from enemy flanking fire. (4)

Terreplein: Originally the gently sloping ground behind a parapet; later became the natural ground surface of a fortified work from which guns and troops operated, protected by an artificial parapet. (4)

Tuesas: Historical spanish measuring unit. 1 tuesa = 66 inches. (EBC)

Varas: Historical spanish measuring unit. 1 varas = 33 inches. (EBC)

Vigas: Evenly spaced rafters (beams) used for flat roofs or ceilings. (6)

Wicket door: A small door or gate forming part of a large one. (8)

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SELECTED HISTORIC DRAWINGS

LIST OF SELECTED HISTORIC DRAWINGS AND CREDITS

1. Sketch of El Morro and San Cristóbal based on the Plan of the City by Engineer Luis Venegas Osorio, 1678. (Archives General de Indies. Mapas Y Planos, Santo Domingo, No. 74.)

2. Plan of San Cristóbal and outworks showing existing conditions and new proposals, August 1702. Author unknown. (General Archive of México, Royal Orders, vol. XXI, Expediente 123.)

3. Plan and section of the Castle of San Felipe del Morro, 1742. (Servicio Histórico Militar, Madrid; sign. 5750:k-b-2-58.)

4. Proposed modernization plan of San Cristóbal by Thomas O'Daly, 1765. (Servicio Geográfico del Ejército, Madrid. Cart. Ultr. X, cat. 68.)

5. Proposed modernization plan of El Morro by Thomas O'Daly, 1765. (Servicio Geográfico del Ejército, Madrid. Cart. Ultr. X, cat. 65.)

6. Existing condition plan, San Cristóbal, May 17, 1765 by Thomas O'Daly. (Servicio Geográfico del Ejército, Madrid. Cart. Ultr. X, cat. 68.)

7. Existing condition plan, El Morro, May 17, 1765 by Thomas O'Daly. (Servicio Geográfico del Ejército, Madrid. Cart. Ultr. X.)

8. Proposed plan of San Cristóbal by Thomas O'Daly, January 15, 1769. (Servicio Geográfico del Ejército, Madrid. Cart. Ultr. X.)

9. Plan of San Cristóbal by Thomas O'Daly. Ca. 1769. (Servicio Histórico Militar, Madrid.)

10. Plan of the City of San Juan by Thomas O'Daly, August 31, 1772. (Servicio Histórico Militar, Madrid. Num. 5748.)

10a. Detail of the Plan of the City of San Juan by Thomas O'Daly, August 21, 1772. (Servicio Histórico Militar, Madrid. Num 5748.)

11. Section of San Carlos Ravelin by Thomas O'Daly, February 26, 1773. (Servicio Histórico Militar, Madrid.)

12. Elevation with the North Bastion and North Walls of San Cristóbal by Thomas O'Daly, February 26, 1773. (Servicio Histórico Militar, Madrid.)

13. Elevation of the south walls of San Cristóbal looking north, cut through the Plaza de Armas and showing the Troops' Quarters. Thomas O'Daly, February 26, 1773. (Servicio Histórico Militar, Madrid.)

14. Elevation of the east walls of San Cristóbal looking west. Section through the North Bastion showing arched supports. Thomas O'Daly, February 26, 1773. (Servicio Histórico Militar, Madrid.)

15. Elevation of the east walls of San Cristóbal looking west and including la Trinidad Counterguard and San Carlos Ravelin. Thomas O'Daly, February 26, 1773. (Servicio Histórico Militar, Madrid.)

16. Plan of San Cristóbal by Thomas O'Daly, August 8, 1773. (Servicio Geográfico del Ejército, Madrid. Cart. Ultr. X, cat. 69.)

17. Section through Fort el Abanico, San Cristóbal by Thomas O'Daly, February 26, 1773. (Servicio Histórico Militar, Madrid.)

18. Plan of the City of San Juan by Juan Mestre, September 13, 1783. (Servicio Histórico Militar, Madrid. Num. 5793.)

19a. Plan of the north city walls by Juan Mestre, September 13, 1783. (Museo Naval de Madrid, K-b-2-58.)

19b. Plan of San Cristóbal and outworks by Juan Mestre, September 13, 1783. (Servicio Histórico Militar, Madrid.)

19c. Detail of September 13, 1783 plan showing northern portion of San Cristóbal. Juan Mestre. (Servicio Histórico Militar, Madrid.)

19d. Plan of the eastern defenses of San Cristóbal including el Abanico and la Princesa by Juan Mestre, September 13, 1783. (Servicio Histórico Militar, Madrid.)

20. Proposed plan of el Morro and the western city walls by Juan Mestre, 1784. (Servicio Histórico Militar, Madrid. Num. 5807.)

20a. Detail of the proposed plan of el Morro and the city walls by Juan Mestre, 1784. (Servicio Histórico Militar, Madrid. Num. 5807.)

21. Existing conditions plan of el Morro and the southern city walls by Juan Mestre, May 12, 1787. (Servicio Histórico Militar, Madrid.)

21a. Existing conditions section through el Morro by Juan Mestre, May 12, 1787. (Servicio Histórico Militar, Madrid.)

22. Section through el Morro by Juan Mestre, May 17, 1787. (Servicio Histórico Militar, Madrid.)

23. Plan of the City of San Juan by Juan Mestre, November 17, 1792. (Servicio Histórico Militar, Madrid. Num. 5795.)

24. Plan and section of the plaza of el Morro by Felipe Ramírez, 1793. (Servicio Geográfico del Ejército, Madrid. Cart. Ultr X, cat. 66.)

25. Plan of la Princesa by Felipe Ramírez, September 28, 1795. (Servicio Histórico Militar, Madrid.)

26. Plan of the City of San Juan by Rafael Clavijo y Pla, ca. 1852-1860. (Servicio Geográfico del Ejército, Madrid. Cart. Ultr. X, cat. 60.)

27. Plan of the City of San Juan by F. Roldán y Navarro, 1887. (Servicio Geográfico del Ejército, Madrid. Cart. Ultr. X, cat. 61.)

28. Roof plan of el Morro by Manuel Castro, 1861. (Library of Congress, Fortifications Map File, Drawer 107, Washington D.C.)

29. First floor plan of el Morro by Manuel Castro, 1861. (Library of Congress, Fortifications Map File, Drawer 107, Washington D.C.)

30. Detail of first floor plan of el Morro by Manuel Castro, 1861. (Library of Congress, Fortifications Map File, Drawer 107, Washington D.C.)

31. Elevations and sections of el Morro by Manuel Castro, 1861. (Library of Congress, Fortifications Map File, Drawer 107, Washington D.C.)

32. Roof plan of San Cristóbal by Manuel Castro, 1861. (Library of Congress, Fortifications Map File, Drawer 107, Washington D.C.)

33. Second floor plan of San Cristóbal by Manuel Castro, 1861. (Library of Congress, Fortifications Map File, Drawer 107, Washington D.C.)

34. First floor plan of San Cristóbal by Manuel Castro, 1861. (Library of Congress, Fortifications Map File, Drawer 107, Washington D.C.)

35. West elevation of San Cristóbal by Manuel Castro, 1861. (Library of Congress, Fortifications Map File, Drawer 107, Washington D.C.)

36. Section through the Plaza de Armas showing elevation of the Troops' Quarters at San Cristóbal. Manuel Castro, 1861. (Library of Congress, Fortifications Map File, Drawer 107, Washington D.C.)

37. Section through the Plaza de Armas looking north and showing the North Casemates at San Cristóbal. Manuel Castro, 1861. (Library of Congress, Fortifications Map File, Drawer 107, Washington D.C.)

38. Section through the Troops' Quarters looking east, San Cristóbal. Manuel Castro, 1861. (Library of Congress, Fortifications Map File, Drawer 107, Washington D.C.)

39. Details of the Chapel and Well House on the Plaza de Armas of San Cristóbal. Votive statue believed to represent St. Barbara. Manuel Castro, 1861. (Library of Congress, Fortifications Map File, Drawer 107, Washington D.C.)

1. Sketch of El Morro and San Cristóbal based on the Plan of the City by Engineer Luis Venegas Osorio, 1678.

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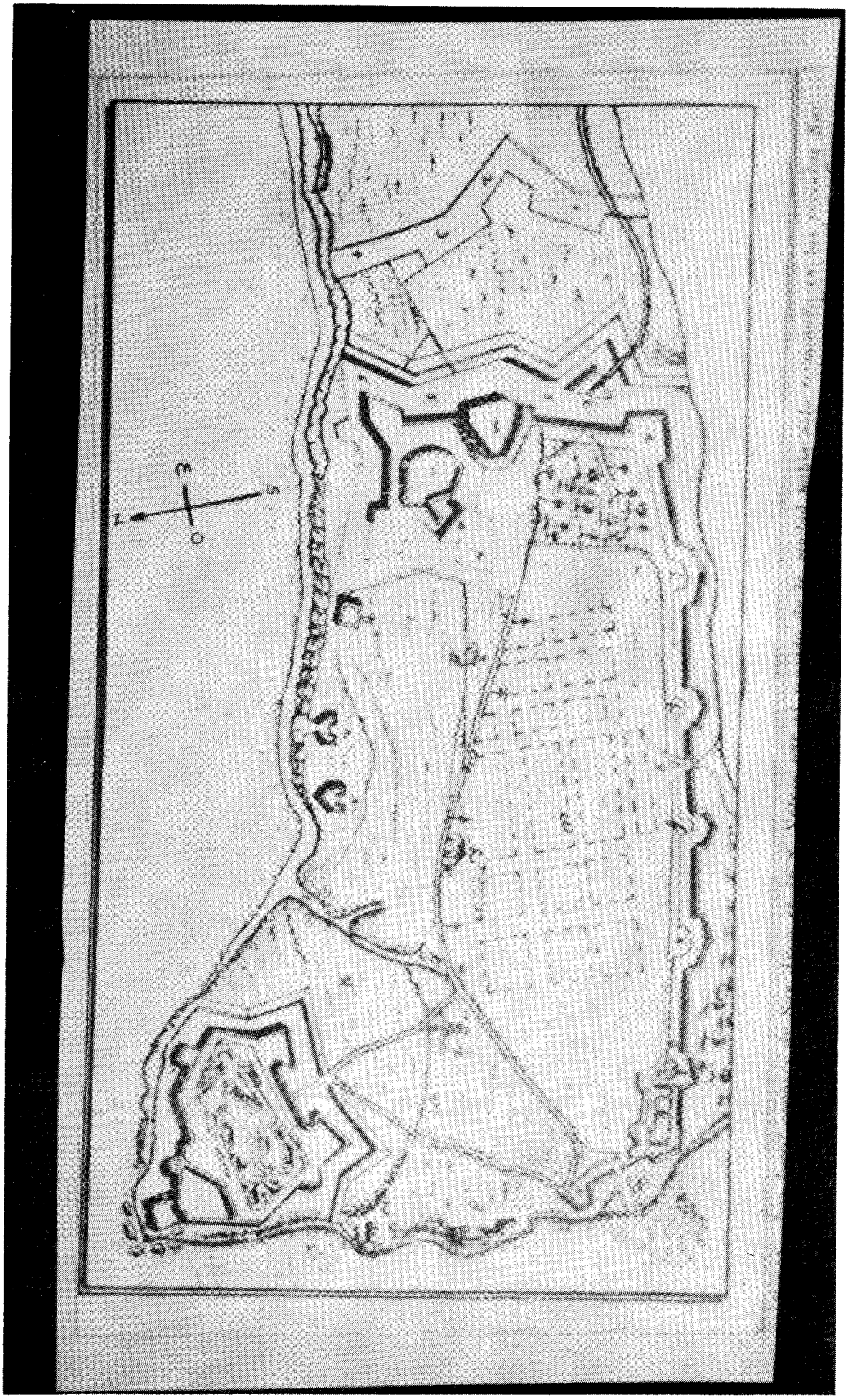
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2. Plan of San Cristóbal and outworks showing existing conditions and new proposals, August 1702. Author unknown.

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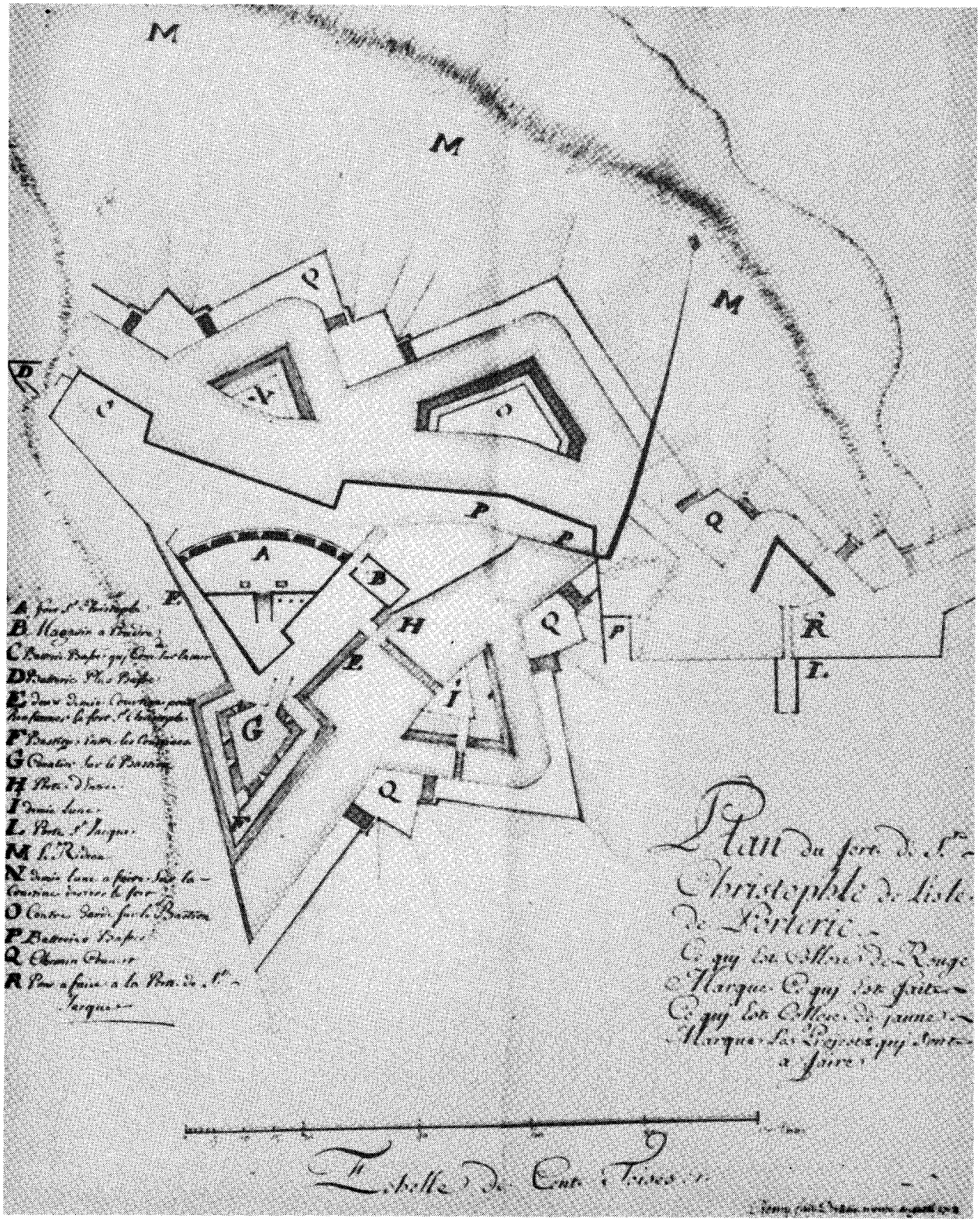
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A fort S.t Christophle
B Magasin a Poudre
C Batterie Basse qui Com. sur la mer
D Batterie Plus Basse
E deux demie Courtines pour transformer le fort S.t Christophle
F Bastion entre les Courtines
G Quatier sur le Bastion
H Porte d'Entrée
I demie lune
L Porte S.t Jacques
M le Rideau
N demie lune a faire sur la Courtine devers le fort
O Contre Garde sur le Bastion
P Batterie Basse
Q Chemin Couvert
R Pont a faire a la Porte de S.t Jacques
Plan du fort de S.t Christophle de l'isle de Porterie
Ce qui est Colloré de Rouge Marque Ce qui est faite
Ce qui est Colloré de jaune Marque les Projets qui sont a faire
Echelle de Cent Toises

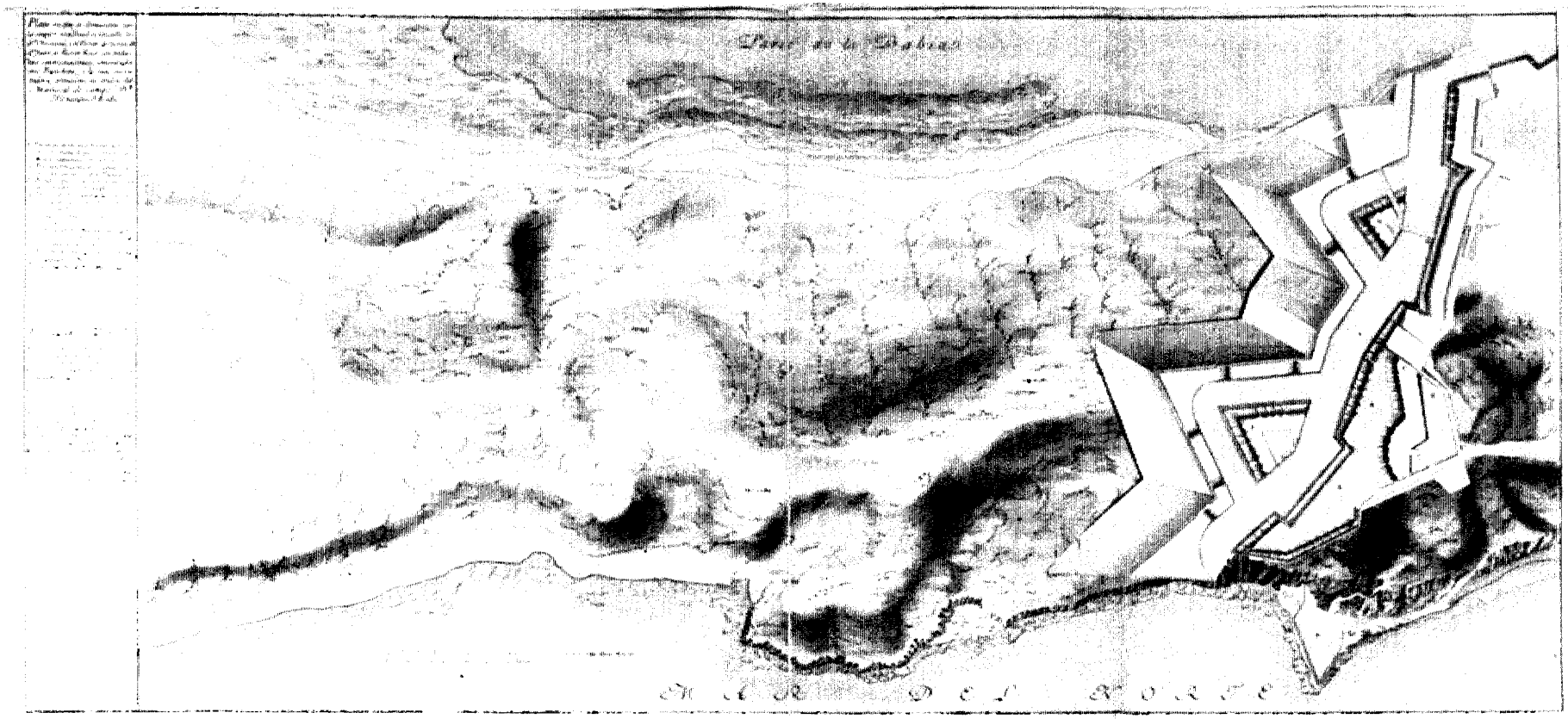
3. Plan and section of the Castle of San Felipe del Morro, 1742.

(following page)

Escala del Plano de 4. Tuesas
Perfil cortado por la Linea 1 2 3 4 5 6 7 8 9 10 11 12
Escala del Perfil de 50 Tuesas

4. Proposed modernization plan of San Cristóbal by Thomas O'Daly, 1765.

(following page)



5. Proposed modernization plan of El Morro by Thomas O'Daly, 1765.

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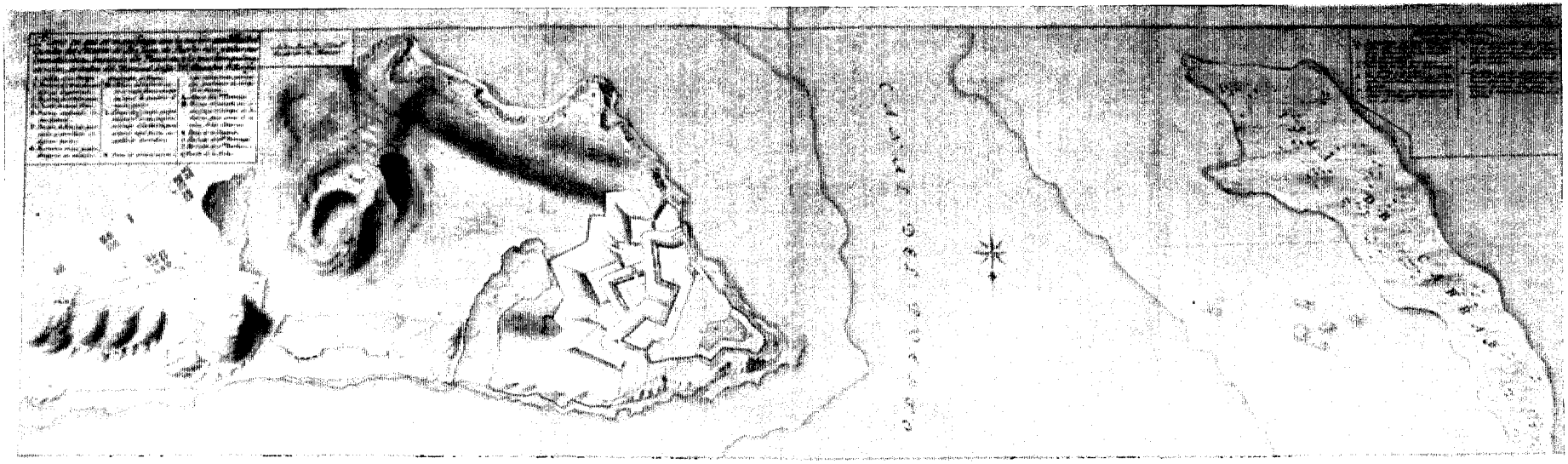

6. Existing condition plan, San Cristóbal, May 17, 1765 by Thomas O'Daly.

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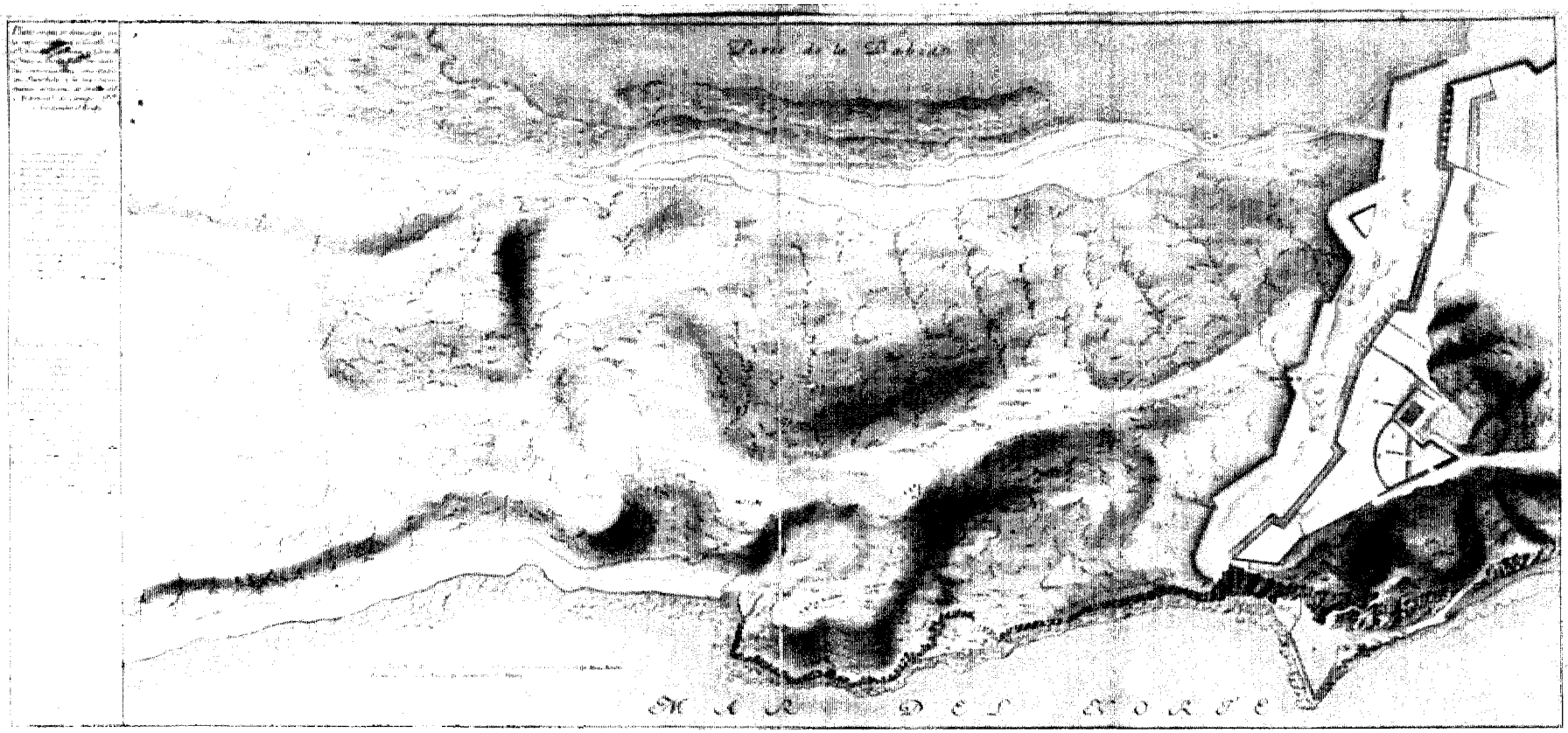
Rade de la Calanque
MER DEL NORTE

7. Existing condition plan, El Morro, May 17, 1765 by Thomas O'Daly.

(opposite page)

8. Proposed plan of San Cristóbal by Thomas O'Daly, January 15, 1769.

(following page)

LEGEND *

Historic Drawing 8

A. New parapets with their embrasures which comprise all the front of the Castle. Two thirds the length of the curtain was raised 6 feet above the old work without including the parapet, and the corresponding terreplein was added. The esplanades will be of hewn stone and some of these are already made.

B. North Bastion with its sentry box of hewn stone which was raised 9 feet without including the parapet.

C. Interior widening of the Castle entirely finished in the form shown, and lacking only the esplanades and four embrasures. This work has at the angle of the sentry box a height of 40 feet, and at the end which is joined with the cavalier it is reduced to 24 feet.

D. Old terreplein of the Castle which in places was raised 3 feet.

E. Communication gallery to Casemate F. This can serve as a countermine to blow up the breach which can be made in the North Bastion and part of the curtain, and likewise to incomode the foothold the enemy might intend to make above.

F. Bomb-proof casemate to defend the moat and Postern giving access to the main moat, and to supplement the small capacity of the flank which allows only one embrasure which because of its height does not defend a portion of the moat.

G. Gate with its bomb-proof vault and a gentle ascent to reach the North Bastion from the main Plaza.

HH. Two magazines for storage of powder, with two floors; only lack the two vaults of the second floor.

I. Underground communication gallery from the interior of the Castle to the moat Postern. This work is done as far as the place which the Plan indicates. This gallery penetrates through rock, but this being of such poor consistency, it is supported by a brick vault.

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*Translated by Richard Crisson, NPS, NARO, BCB.

K. Old cavalier whose platform will be raised 6 feet in order to dominate better the outworks and the terrain in front.

L. Projected Battery in continuation of the cavalier, with five very ample bomb-proof vaults, which will be divided into two floors. The fires of this Battery dominate the circular portion of the counterscarp in front of the North Bastion, with the retrenchment k and covered way g, and likewise part of the terrain which looks on the face of Ravelin W.

M. Ramp for carrying artillery to the cavalier.

N. Projected Battery on the north of the main plaza, in continuation of the two Powder magazines HH, with seven bomb-proof vaults for storage or barracks.

O. Projected bomb-proof cisterns, capable of supplying five thousand persons with water for three months. This is considered of first importance because of having no other sure means of providing this article in time of siege since they have few and none bomb-proof in the city, and to save the continuous expense which is experienced in bringing water in small boats from the surrounding rivers.

P. Well with its communication to the Cistern, covered by a vault under the ramp.

Q. Main entrance to the Castle.

R. Old vault which is allowed to remain for countermining.

S. Executed portion of countermining gallery. This was cut in the live rock, and runs below the level of the Castle's moat in the direction which is shown, to end in the inaccessible precipice under the North Bastion where there will remain only an air-passage very necessary for the ventilation of the whole gallery. From this countermine, because of its being below the level of the
moat, branches can be pushed forward which will catch the enemy miner from below. This and its distance from the facing of the fort preserves it to be ruined at the time that the breach is made with cannon or mine. Finally from this gallery is gained the importance of being able to communicate safely with all the countermines of the exterior works.

T. Design where the work of the gallery is being continued and runs under the communication of the

moat Postern. [Tunnel 2] In the North Bastion it will communicate with a countermine well constructed in the farthest part of Casemate F.

V. Caponier for communication of the Ravelin.

W. New San Carlos Ravelin. It lacks only the parapet and the facing for the stairway from the moat.

X. Two strong vaults in the Ravelin, 42 feet in length and 16 in width. The front of the Ravelin to which these were adjoined is the least exposed to the attack since the enemy batteries would be seen from the rear.

Y. Powder storage, equally strong, for the defense of the Ravelin.

Z. Barrier against rebound batteries to which the south face of the Ravelin is exposed. Also it will be able to protect the dispositions for the defense of the breach that may be made in the face that looks to the north.

a. Main moat, the excavation made and to be made will be seen by Profile No. 2, letters L, M. The quality of the terrain is a soft rock which was cut in places up to 20 feet with the same talus as the old work laid above. For greater strength, all the face and flank of the North Bastion was reinforced, and the same is being done in the curtain.

b. Moat of the Ravelin which has on the north side 10 tuesas of width and on the south 7, due to the steepness of the terrain in front, as shown in Profile No. 1, letter B and Profile No. 4.

c. Demi-caponiers or traverses to defend the moat of the Ravelin, as shown by Profile No. 4.

d. Projected countermining gallery; will have its entrance at the level of the moat between the staircases of the Ravelin.

e. Countermine begun in the re-entrant angle of the counterscarp. This will run at the level of the moat under the parapet of the covered way, with branches in
order to blow up the ground behind the crest of the glacis. It also will receive its ventilation in the coastal cliff. At the level of the covered way will be

extended branches which should be blown before the lower mines, succeeding by this means in blowing the same earth twice.

f. Ramp for ascending the Ravelin.

g. Staircase for ascending the Ravelin when the ramp is exposed as a result of the breach made in its north face.

h. Barrier of the Plaza de Armas south of the Ravelin, which requires this protection because of the steep slope of the terrain.

i. Half of the Plaza de Armas (h) higher than the other behind the barrier.

k. Projected redoubt in front of the North Bastion to supplement the small defense which, because of the steepness of the terrain, is drawn from the parapets of the Bastions and the Ravelin, and for the same reason more exposed to the attacks of the besieger.

l. A portion of glacis on the north very precipitous making passage on that side impossible.

m. Very precipitous terrain which was begun to be escarped.

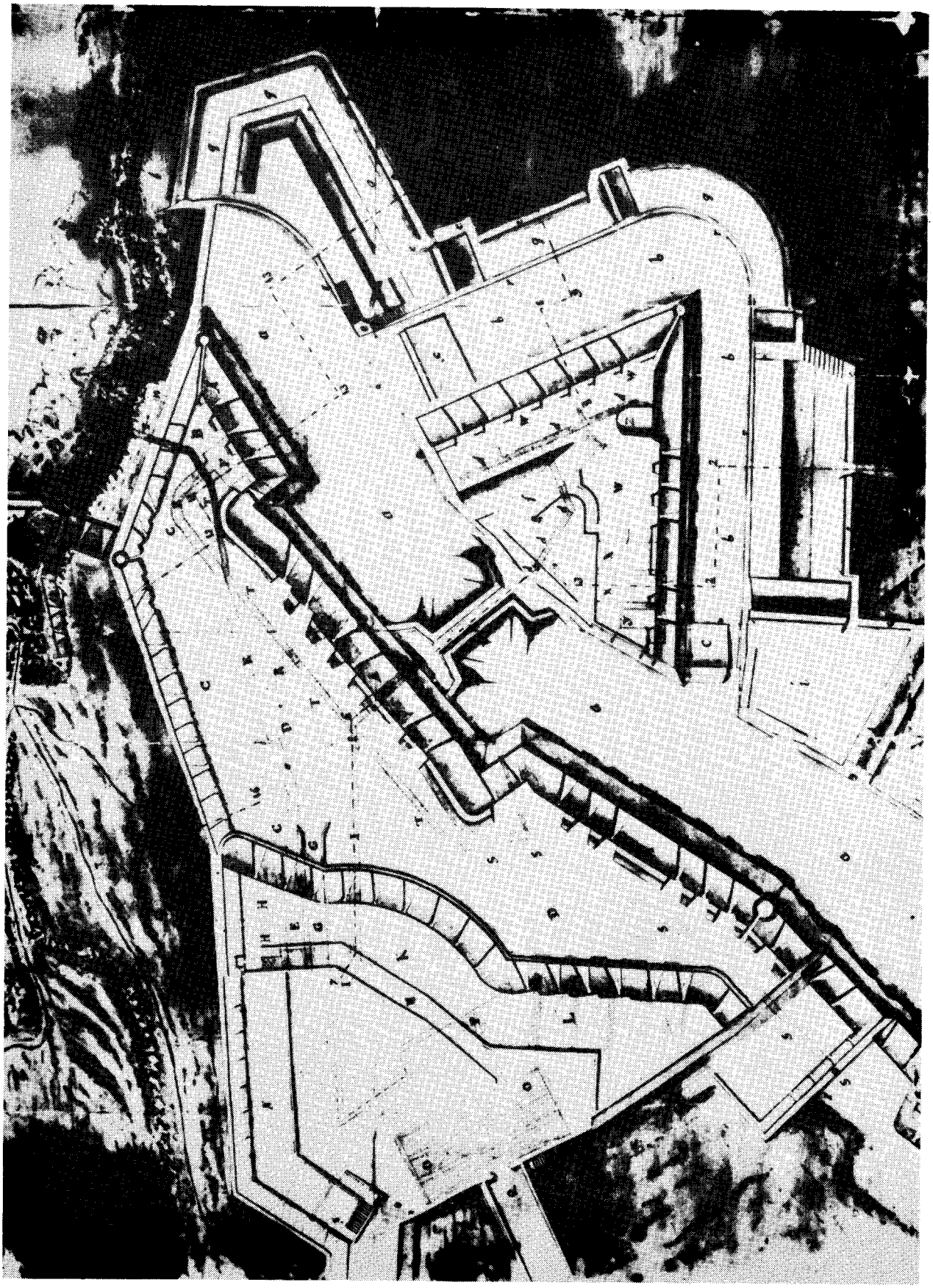
n. Old post for soldiers north of the North Bastion which, because of its narrowness and weakness, is intended to be demolished as soon as the fire of the projected post (o) can be effective.

o. Projected post for soldiers that in the form shown, could flank the defenseless portion of the face of the Bastion, the cliff below the moat and the margin of the coast not covered by the fort.

p. The Fort on the Point or Espigón.

q. Covered way which is begun in front of the Ravelin.

r. Counterscarp begun, and in places lacking only 7 feet of its height.



9. Plan of San Cristóbal by Thomas O'Daly. Ca. 1769.

(following)

LEGEND *

Historic Drawing 9

Undated but very similar to O'Daly's Jan 15, 1769 plan. Titled, "Plan of the San Cristóbal Castle, & of the Work which is added."

A. Old Cavalier which will be raised 20 feet over the curtain of the castle wall.

B. To the Right, with 6 bombproofs, with upper and lower quarters.

C. Door for help, for when the enemy has breeched and the main gate is barricaded.

D. [Bomb] "proofed" cistern for rations needed for one year for 4000 men.

E. To the right of the cavalier.

F. Another [vault] for communication with the casemate whose canon facilitates watching the enemy which is entrenched on the slope, and [watching] our own soldiers in their retrenchment.

G. Another [vault] in which is located the ramp up to the fort (Cavalier?)

H. Another [vault] which leads to the sally-port of the Ravelin.

I. Another 5 [vaults] for quarters.

K. Two identical [vaults] for kitchens and latrine, which serves as a (water) outlet for the upper platform, with which it is maintained clean.

L. "Hidden Pipe" for the use of water for the kitchens.

M. Part of the entrance ramp.

N. Lower flank for the Santiago Curtain.

O. Another (flank) for the same.

P. Part of the Santiago Curtain.

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*Translated by Richard Crisson, NPS, NARO, BCB.

Q. Entrance for the principal countermine which is in the direction of the line (shown in) red.

R. San Carlos Ravelin.

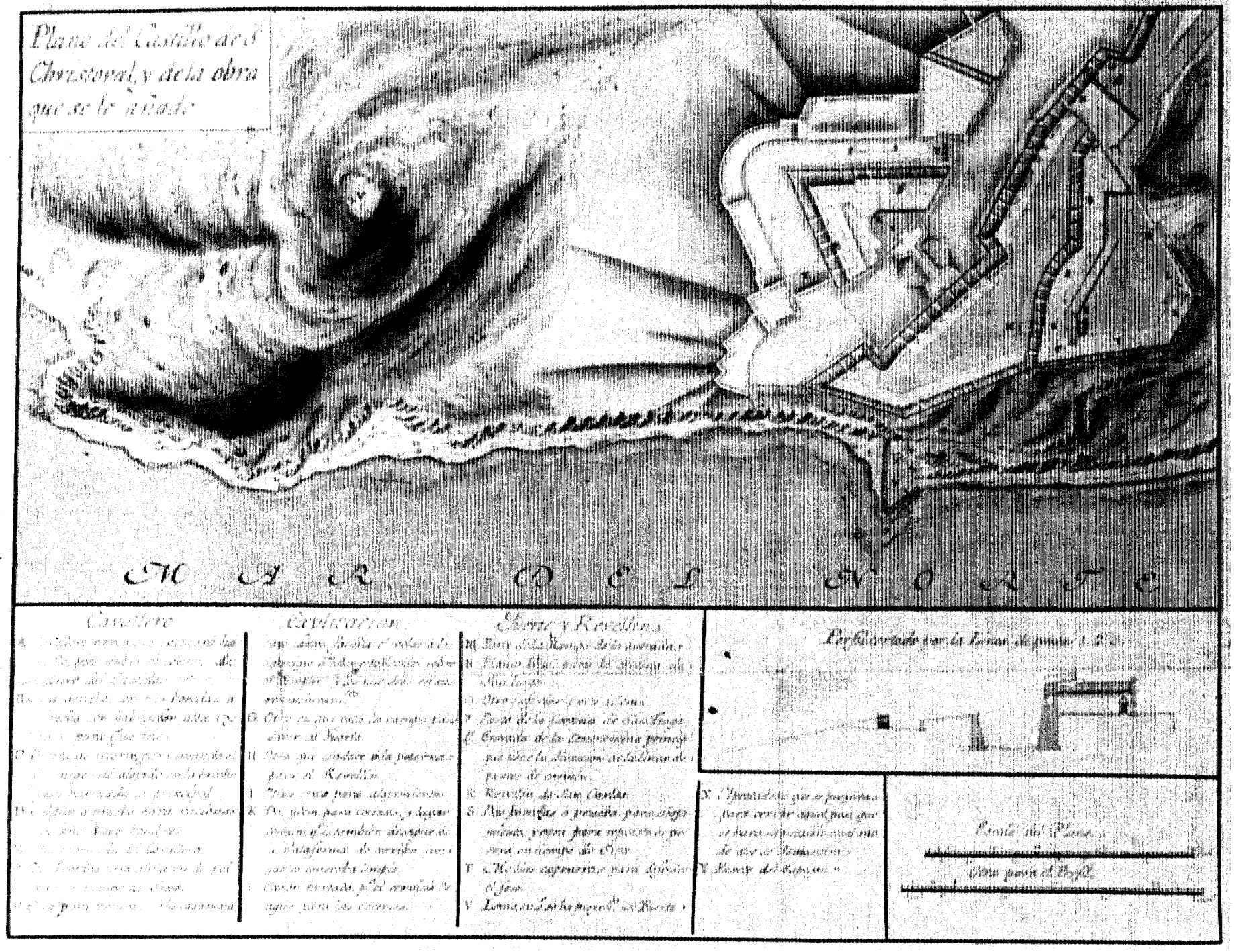
S. Two bombproofs (one) for quarters and the other for emergency powder in times of siege.

T. Demi-caponiers (traverses) for moat defense.

V. Hill on which a fort is projected. (note: site of El Abanico)

X. Fuel station? Dock-Yard? which is projected to close access which will be made inaccessible in the manner shown.

Y. Fort of the Espigón.


Plano del Castillo de S. Christoval, y de la obra que se le añade
MAR DEL NORTE
Cavallero
Explicacion
Fuerte y Revellin
Perfil cortado por la Linea de puntos 1 2 3
Escala del Plano
Otra para el Perfil

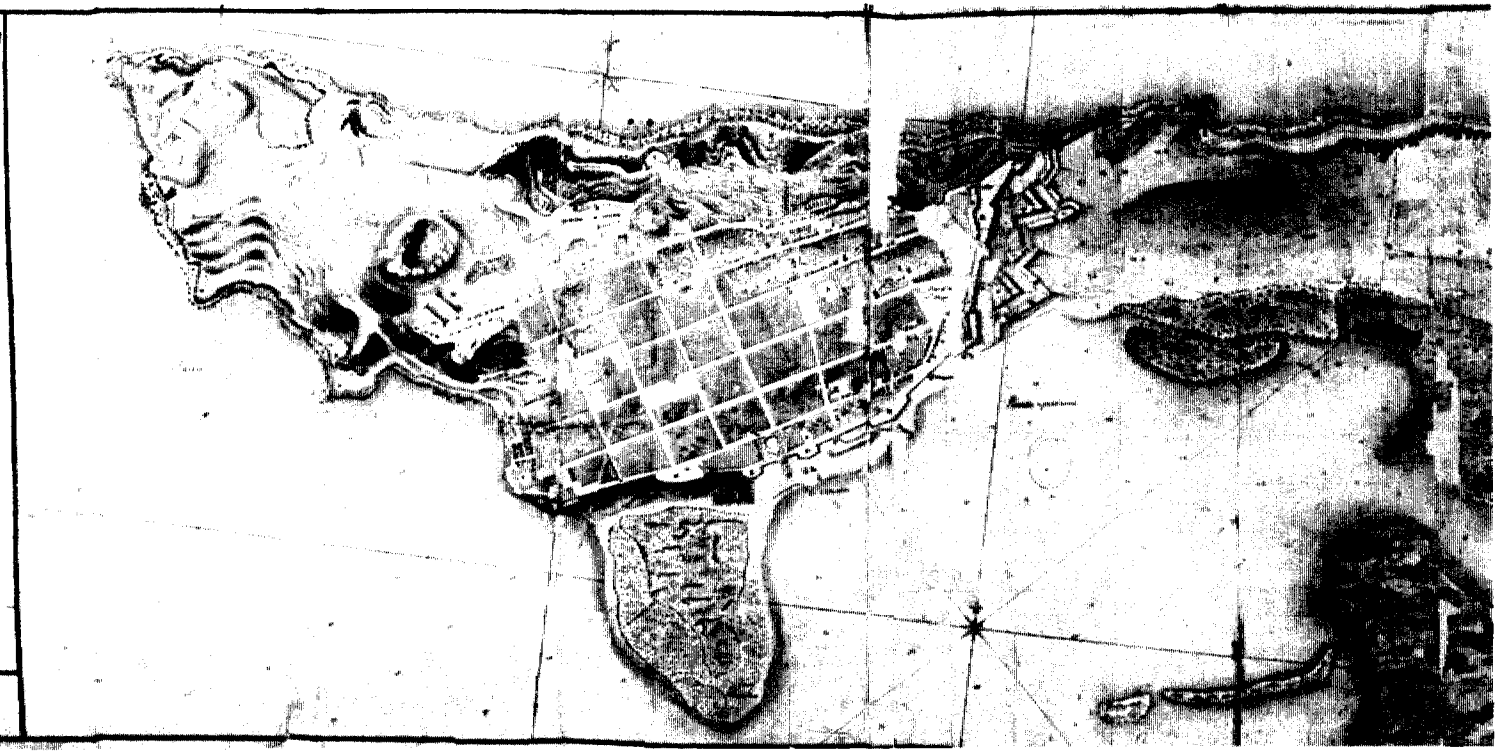
10. Plan of the City of San Juan by Thomas O'Daly, August 31, 1772.

(following page)

10a. Plan of the City of San Juan by Thomas O'Daly, August 31, 1772. (Detail)

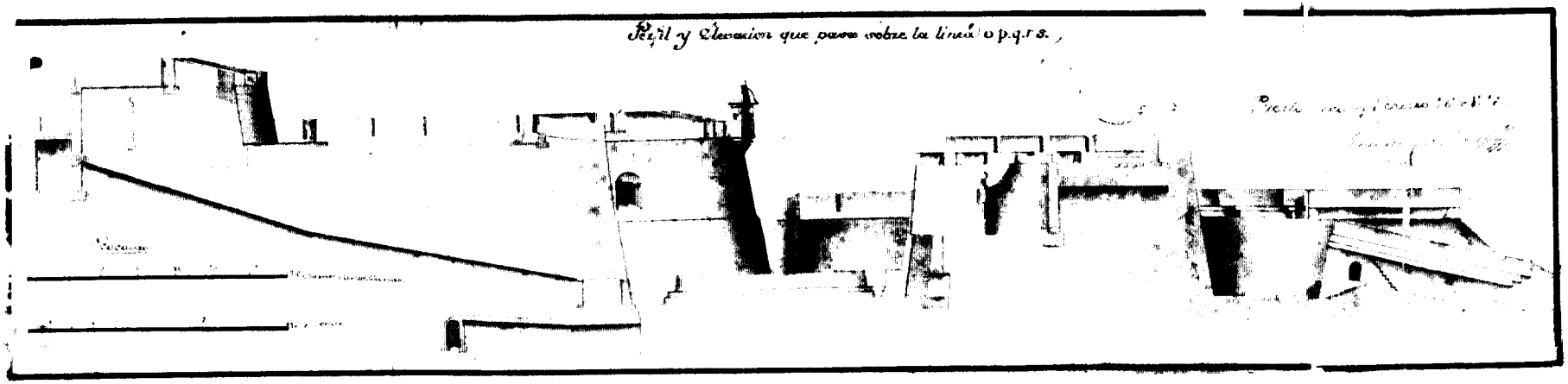
(following page)

Plano de la Plaza de S.t Juan



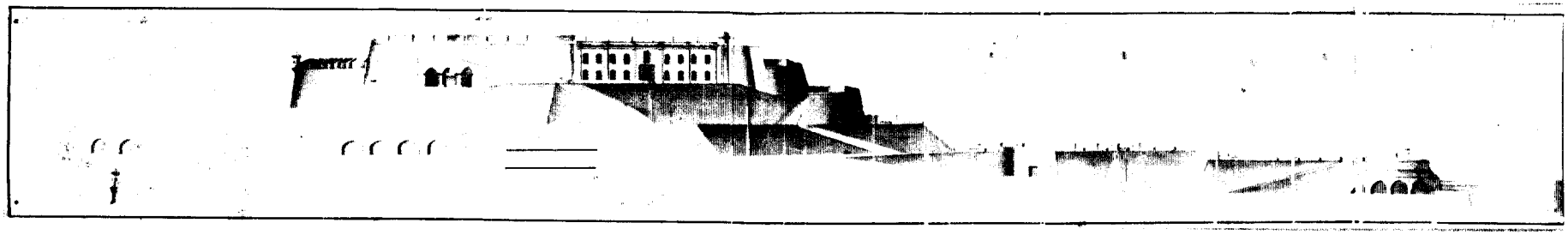
11. Section of San Carlos Ravelin by Thomas O'Daly, February 26, 1773.

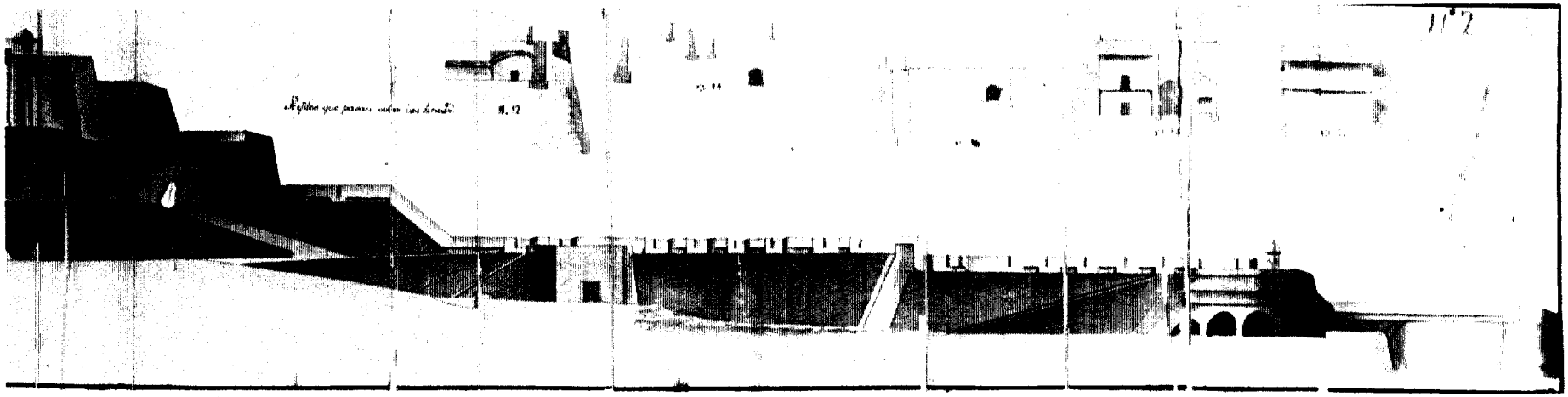
(following page)


Perfil y Elevacion que pasa sobre la linea o p q r s.

12. Elevation with the North Bastion and North Walls of San Cristóbal by Thomas O'Daly, February 26, 1773.

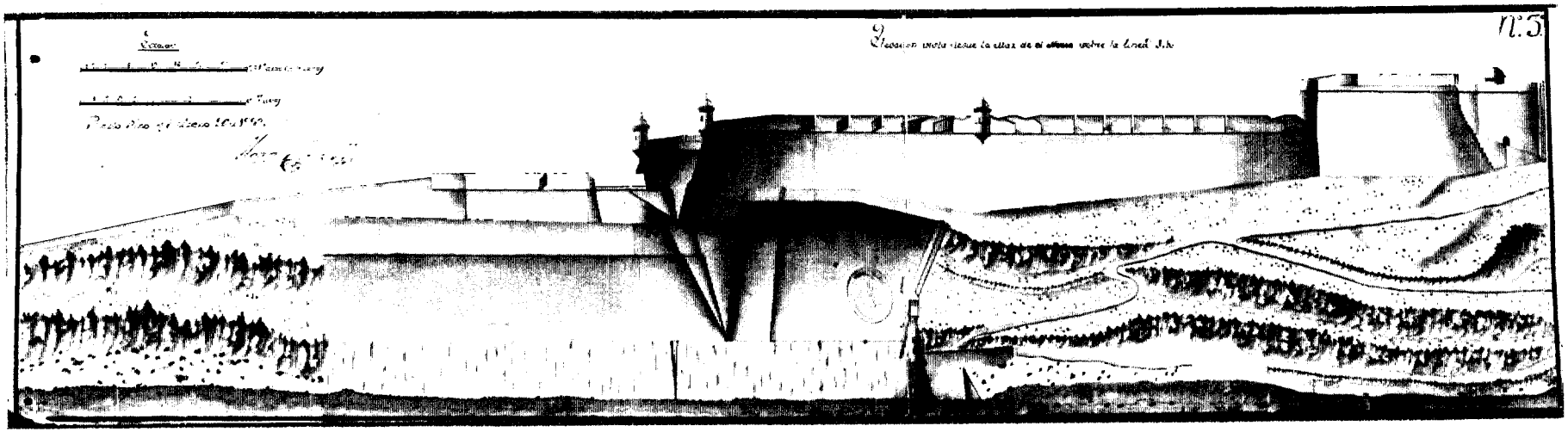
(following page)





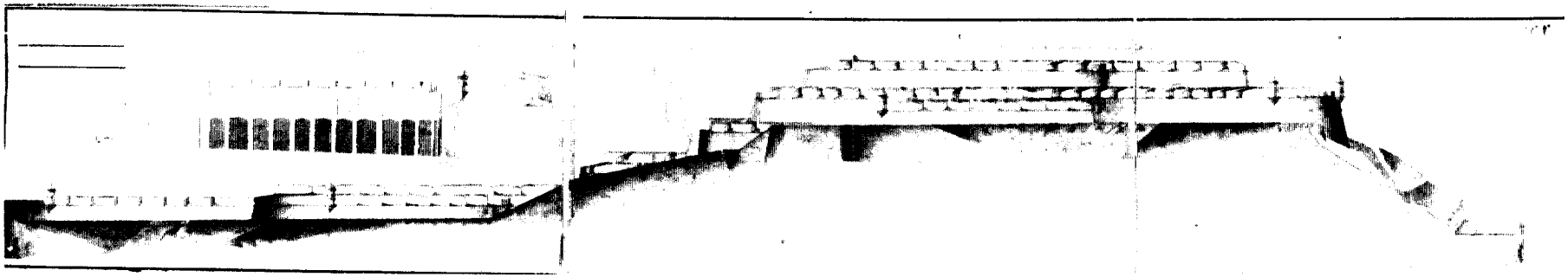
13. Elevation of the south walls of San Cristóbal looking north, cut through the Plaza de Armas and showing the Troops' Quarters. Thomas O'Daly, February 26, 1773.

(following page)



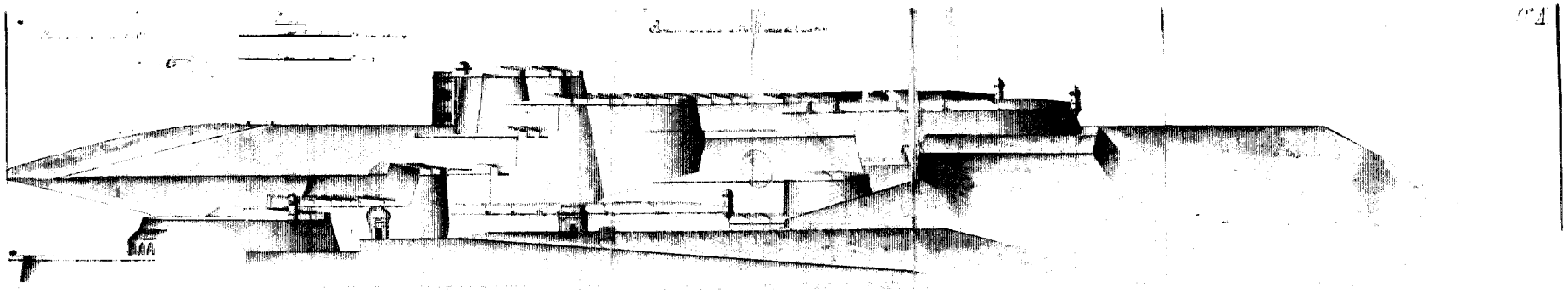
14. Elevation of the east walls of San Cristóbal looking west. Section through the North Bastion showing arched supports. Thomas O'Daly, February 26, 1773.

(following page)



15. Elevation of the east walls of San Cristóbal looking west and including la Trinidad Counterguard and San Carlos Ravelin. Thomas O'Daly, February 26, 1773.

(following page)



16. Plan of San Cristóbal by Thomas O'Daly, August 8, 1773.

(following)

LEGEND *

Historic Drawing 16

Plan of San Cristóbal, Aug. 8, 1773, by Thomas O'Daly titled; "San Juan, Puerto Rico, According to the Project Approved by Your Majesty in the Year 1765"

A. North Bastion.

B. South Bastion.

CC. Low batteries of the South Bastion.

D. Santiago Gate.

E. Santiago Bastion.

F. Work raised with powder (magazine) supply to support the terreplein of the Bastion.

G. Cavalier with its ramp.

H. Gate of the Castle.

II. Gallery for communication to the casemate under the North Bastion, which can be used for countermines.

KK. Postern whose gallery can also be used for countermining.

LL. Bomb-proof Powder Magazines in two levels.

M. Postern under the Cavalier.

N. Five bombproofs with two levels, which can be used as quarters, with its communication circular staircase.

O. Projected cisterns.

P. Appropriate space for five bomb-proofs with a battery above.

QQ. Countermine Gallery which corresponds to the front of the castle and which terminates in the north face of the North Bastion.

RR. New reinforcement for the loose soil without rigidity on this bastion.

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*Translated by Richard Crisson, NPS, NARO, BCB.

S. Caponier.

T. San Carlos Ravelin, with two bomb-proofs, powder supply and a cistern under the small entrance terreplein.

VV. Traverses or demi-caponiers for defense of the moat with musket fire.

XX. Moats.

Z. Countermining Gallery under the banquette of the covered way.

NOTE The parts of the Cavalier which include the bomb-proofs (N) and the entrance gate (H) are newly constructed and the circular part of this battery is raised over the old formation. All the space included between the Gallery II and the Battery that faces the sea is new work. All of the interior front of this castle is raised over the old section (terreplein) that corresponds to the depth of the moat as shown in the sections and everything related to the project as approved by your Majesty. The post named Espigón is located under the north cliff of the Castle, serving as an outpost to the beach. THe slope in front of San Cristóbal, a distance of 100 varas, was dismantled and the soil was removed to a hollow, 25 feet deep, adjacent to the covered way.

a. Ravelin of the Prince with its gate, vaults for guard troops and supply of powder, all bomb-proof.

b. Countermine gallery.

cc. Traverses against rebound.

ddd. Place of Arms named Trinity, whose terrain had a 55 foot difference thus requiring it to be divided into three useful batteries, under which Magazines and bomb-proof Guard Houses can be cut in the soft stone. The work is surrounded by a narrow moat, without covered way, and with a palisade and a small moat (fosse) in the manner proposed by his Excellency Don Ignasio Sala in his additions to the Treaty of Defense of the Plazas (cities?) by Field Marshall Bauban.

e. Covered Way sloping from the counterscarp in order to leave open the fire (artillery) from the Ravelin and the Battery of the Trinity.

f. Traverse with its glacis as shown, for the defense of the Covered Way and whose parapet with entering and salient angles (redientes) prevents the enfilade.

gg. New Wall with foundations in the sea with the purpose of containing the soil of the glacis so that the (soil) does not form into a beach and to hinder the enemy from wading this passage.

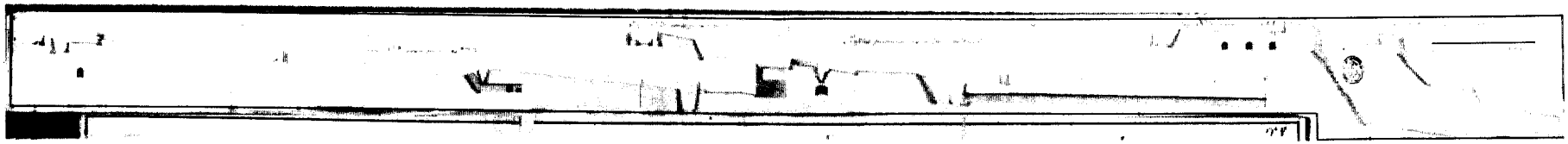
NOTE: All the glacis and covered way in front of Santiago Bastion and Principe Ravelin is a terreplein that has been raised from the level of the sea. Since this covered way was exposed to the rebound and direct fire from the height found in front of San Carlos Ravelin, the redents of the covered way parapet have been constructed as shown by the Plan. The redents, together with the traverses, correct that latter inconvenience and provide on one side, fire parallel to the capital (city), and on the other, parallel to the sea.

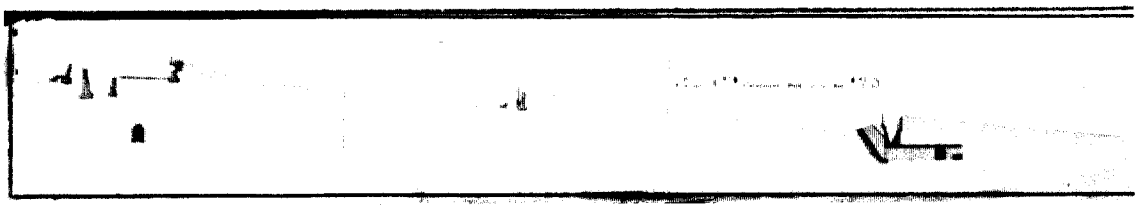
The interior ramps for easiest conveyance of artillery have been arranged in the manner provided by the irregularity of the terrain; their declivities have been covered with sod.

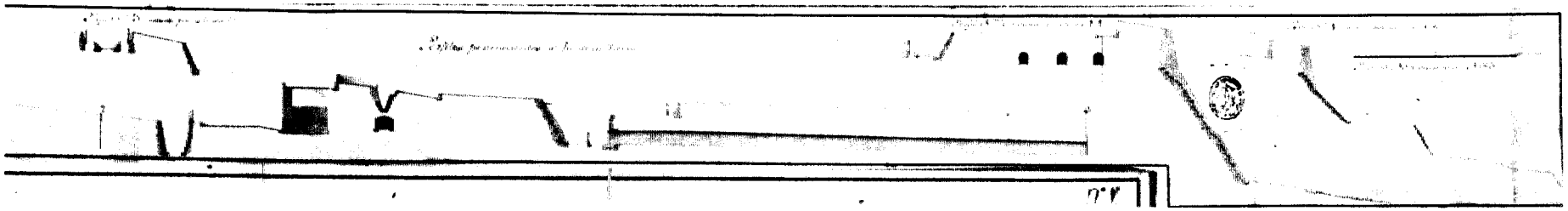
All the esplanades of the batteries are built firmly, half of hewn stone and the remainder of concrete. The interior space of San Cristóbal and the Cavalier is covered with concrete to collect the waters for the cistern. The numbers in the Plan indicate the different elevations above sea level, in Pies de Rey. All the works have embrasures for 113 canons. in the Profiles of the walls, the light carmine red color shows the old works, and the dark carmine the new works.

17. Section through Fort el Abanico, San Cristóbal by Thomas O'Daly, February 26, 1773. (Top: Whole section. Middle: Left side of section enlarged. Bottom: Right side of section enlarged.)

(following page)

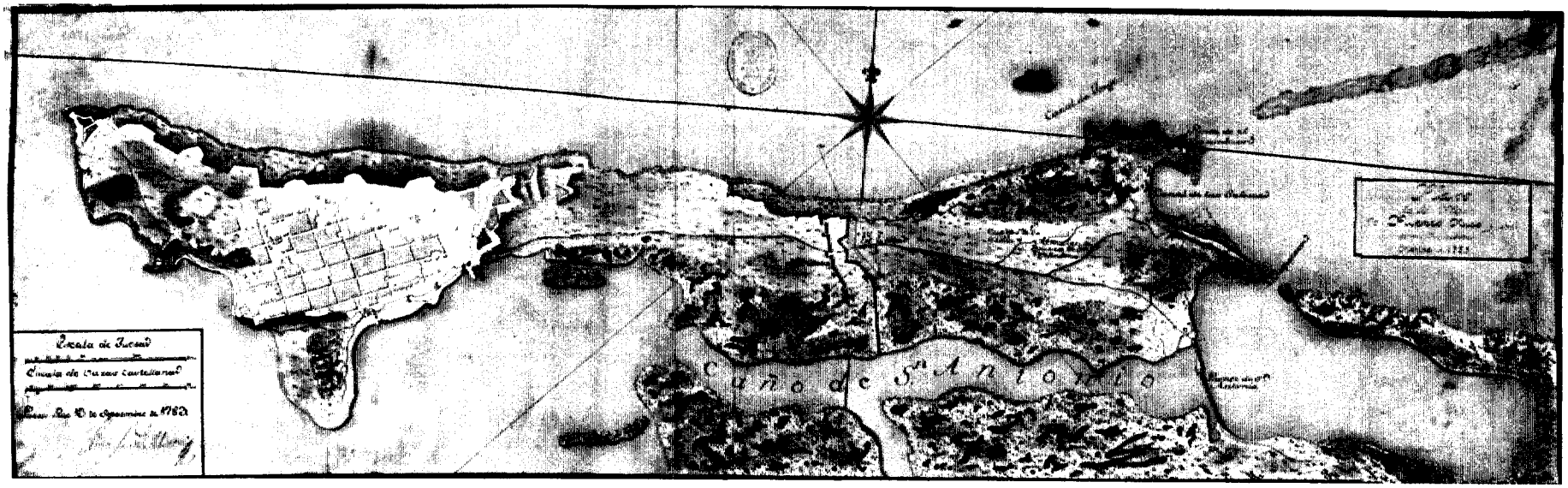






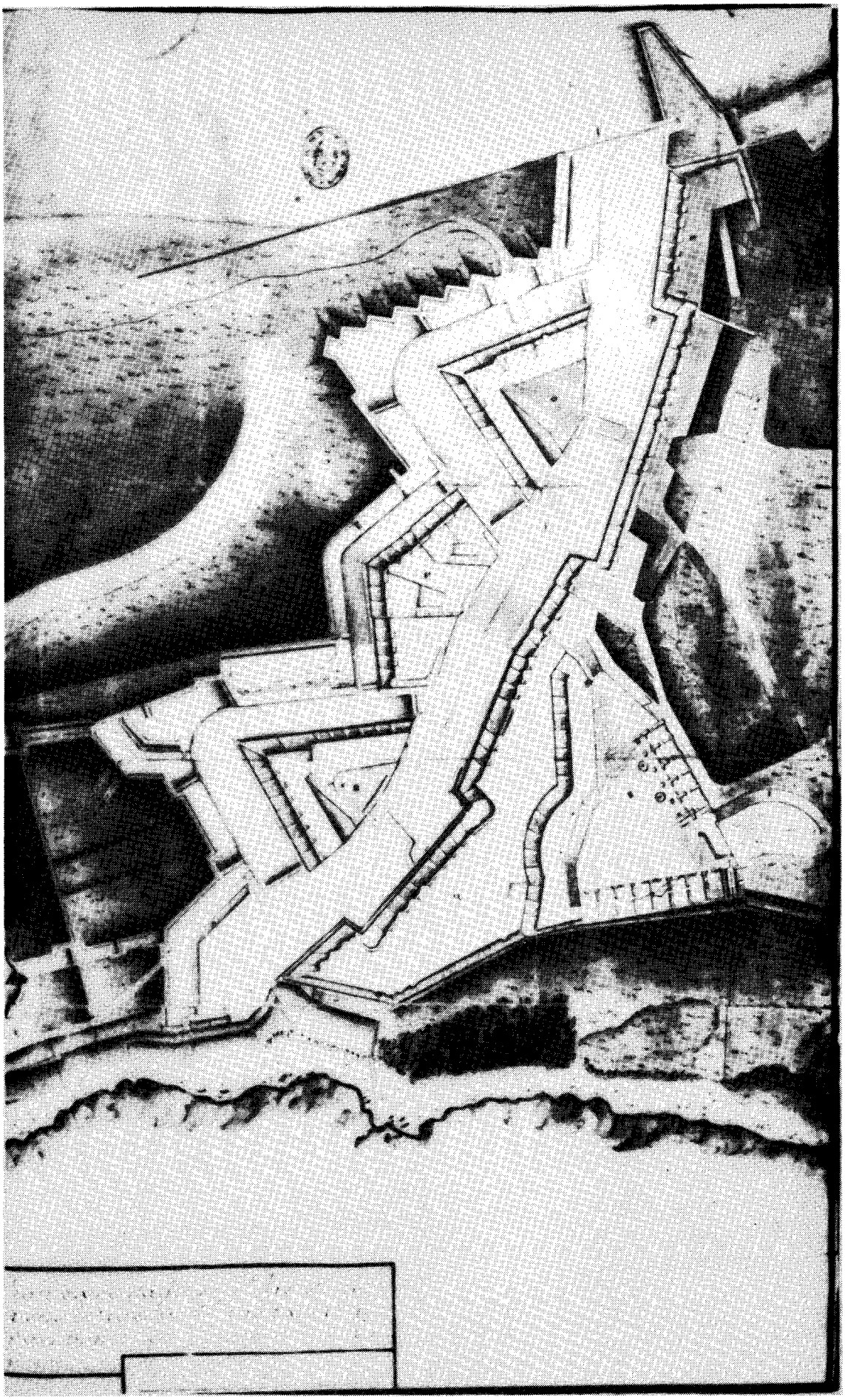
18. Plan of the City of San Juan by Juan Mestre, September 13, 1783.

(following page)


Escala de Tuesas
Escala de Varas Castellanas
Canó de Sn Antonio

19a. Plan of the north city walls by Juan Mestre, September 13, 1783.

(following page)



LEGEND

Historic Drawing 19b and 19c

Plan of San Cristóbal, Sept. 13, 1783, by Engineer Mestre.

L. Moat south of El Principe Ravelin (Santiago).

M. Santiago Bastion.

N. Santiago Gate.

O. El Principe Ravelin (Santiago).

P. Trinity Battery.

Q. San Cristóbal Fort.

R. San Carlos Ravelin.

SS. Intrenched Plaza de Armas of the main covered way.

T. Countermined Santa Teresa Fort.

V. Abanico Fort with vault for troops and powder magazine, everything bomb-proof, and some mine chambers located in the face that looks to the north.

X. Princesa Fort with vault for troops, powder magazine and room for officers, everything bomb-proof.

ZZ. First retreat with fosse, according to the system of Don Ignacio Sala, with all its front countermined and the chambers prepared to blow up everything above.

aa. Second Retreat

b. Espigón.

c. Southwest moat of el Abanico.

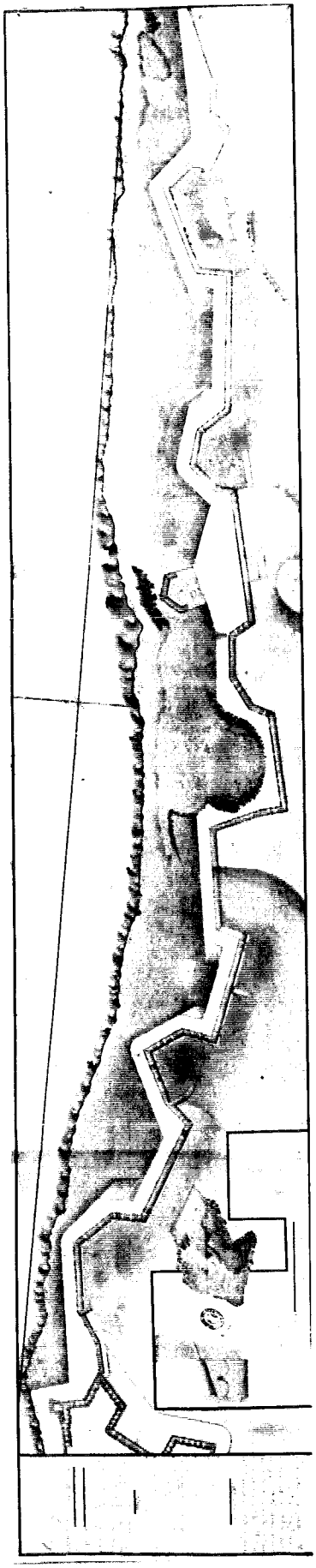
d. Palisade with gate (La Princesa).

e. Masonry breakwater (Tajamar) of la Princesa.

f. Terrain in the form of a ramp (la Princesa).

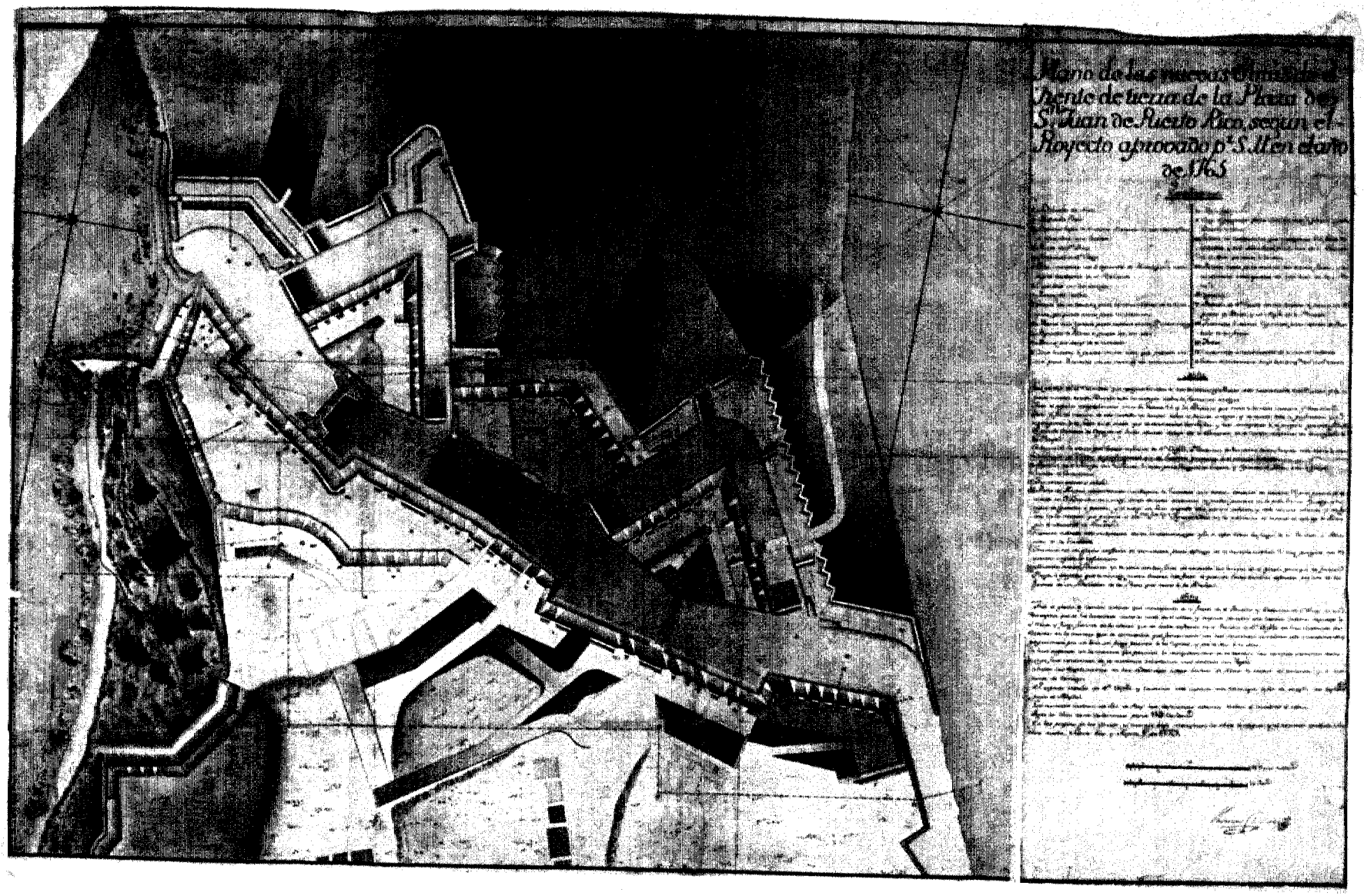
g. Moat south of el Principe Ravelin.

h. Provisional barrier south of Santiago Bastion.



19b. Plan of San Cristóbal and outworks by Juan Mestre, September 13, 1783.

(following)


Plano de las nuevas Obras de
frente de tierra de la Plaza de
S.n Juan de Puerto Rico, segun el
Proyecto aprovado p.r S. M. en el año
de 1765

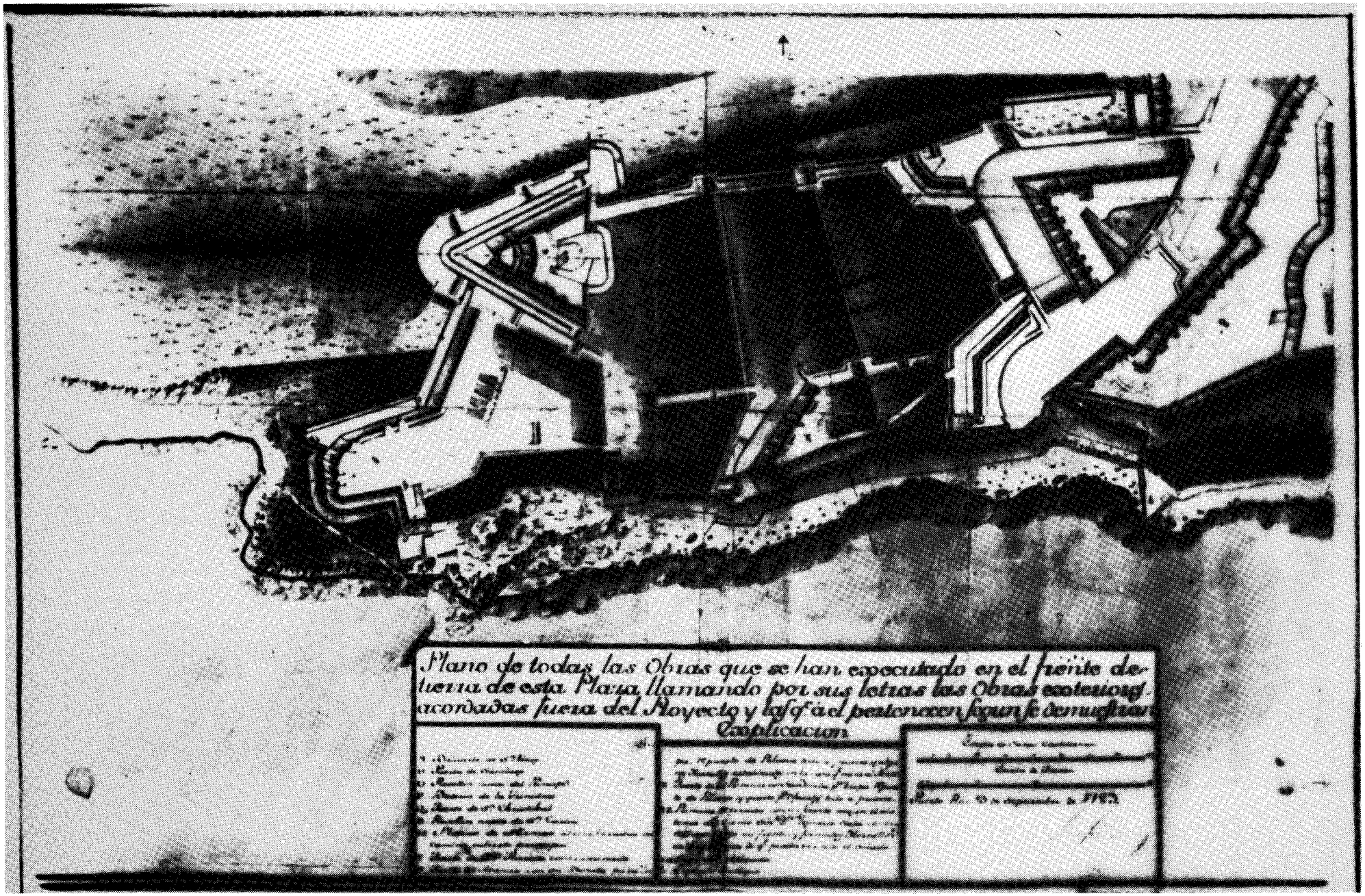
19c. Detail of September 13, 1783 plan showing northern portion of San Cristóbal. Juan Mestre.

(following page)

N

19d. Plan of the eastern defenses of San Cristóbal including el Abanico and la Princesa by Juan Mestre, September 13, 1783.

(following page)

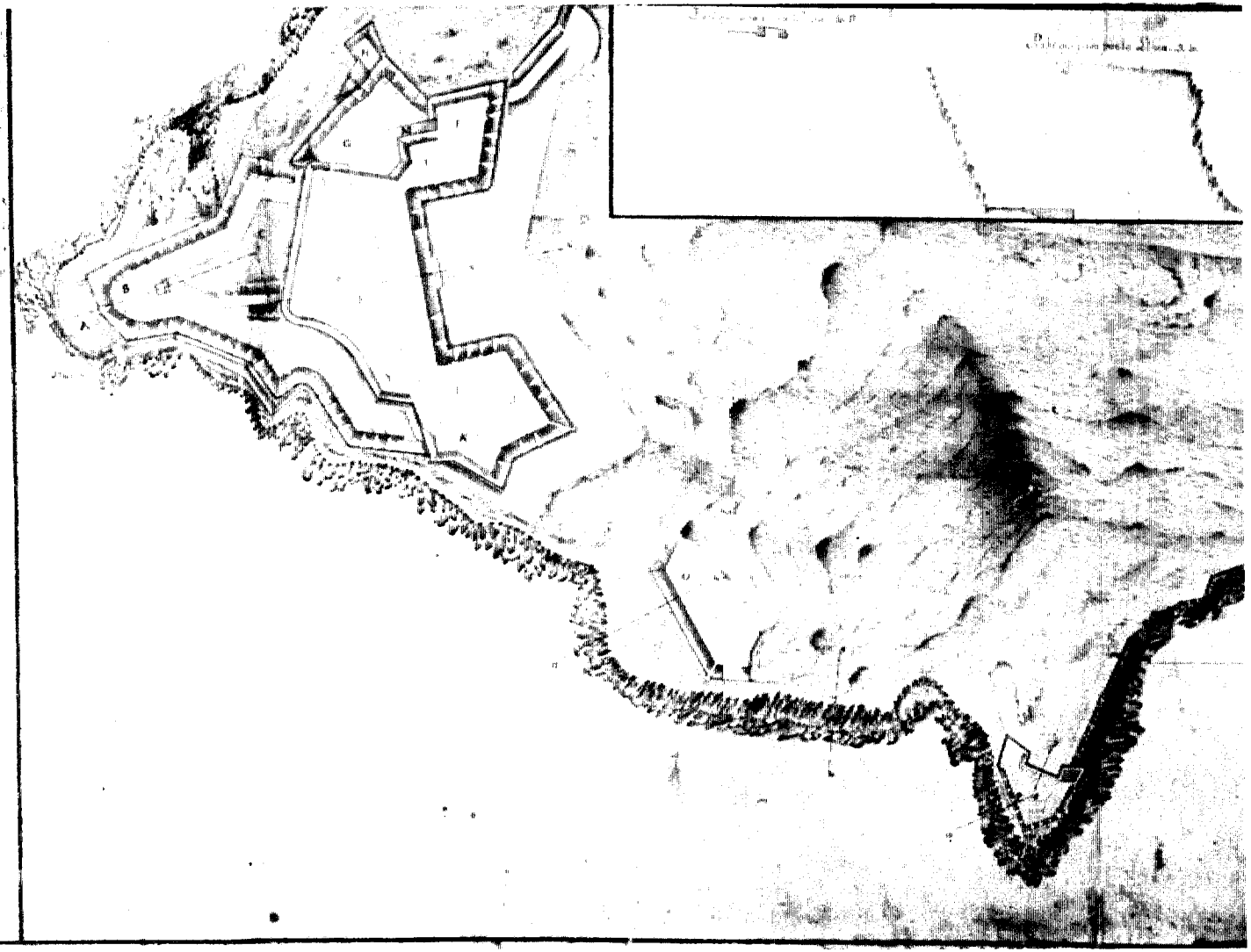

Plano de todas las Obras que se han executado en el frente de-
tierra de esta Plaza llamando por sus letras las Obras exteriorm.
acordadas fuera del Proyecto y las q.e a el pertenecen segun se demuestran
Explicacion

20. Proposed plan of el Morro and the western city walls by Juan Mestre, 1784.

(following page)

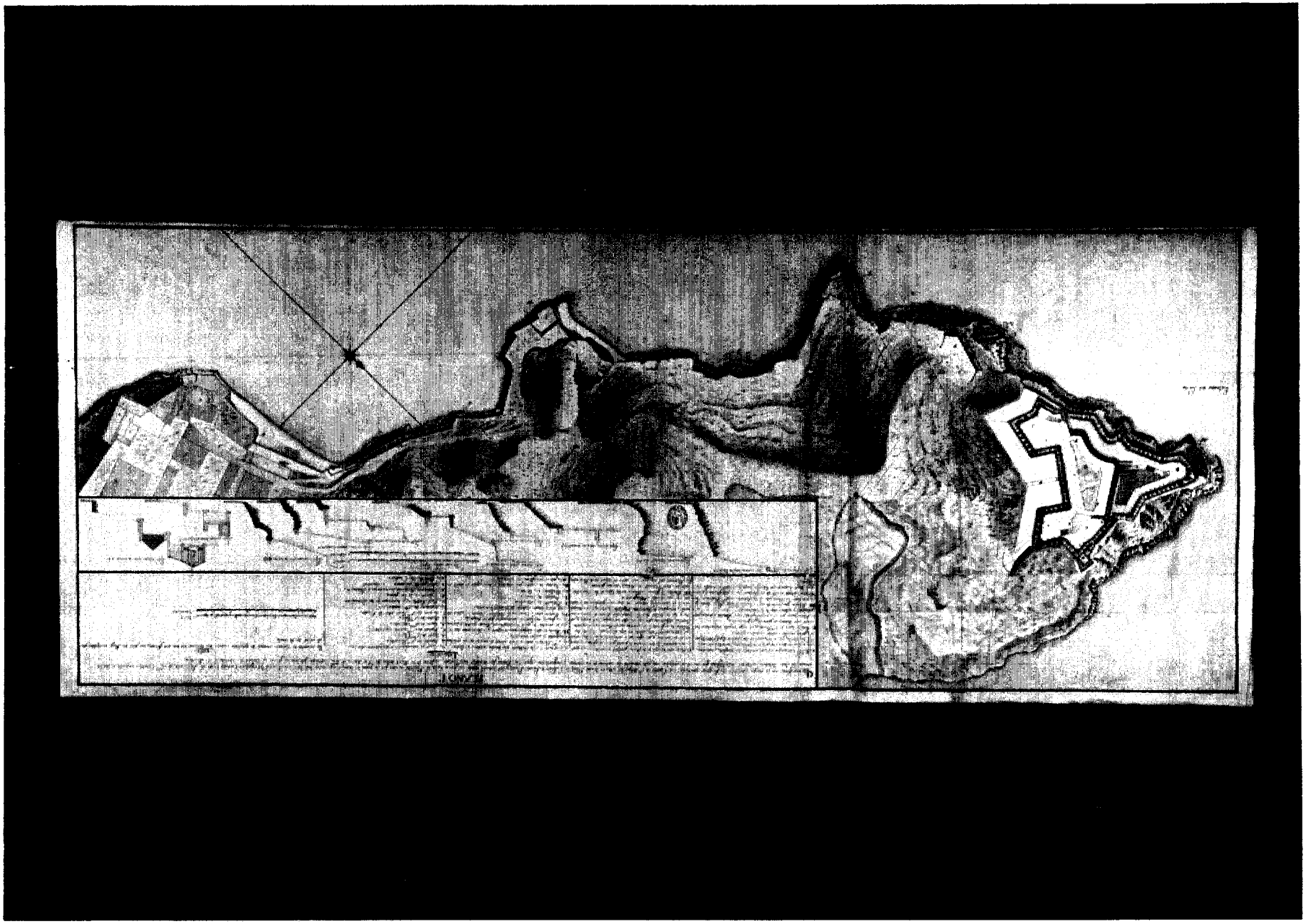
20a. Proposed plan of el Morro and the western city walls by Juan Mestre, 1784. (Detail of no. 20.)

(following page)



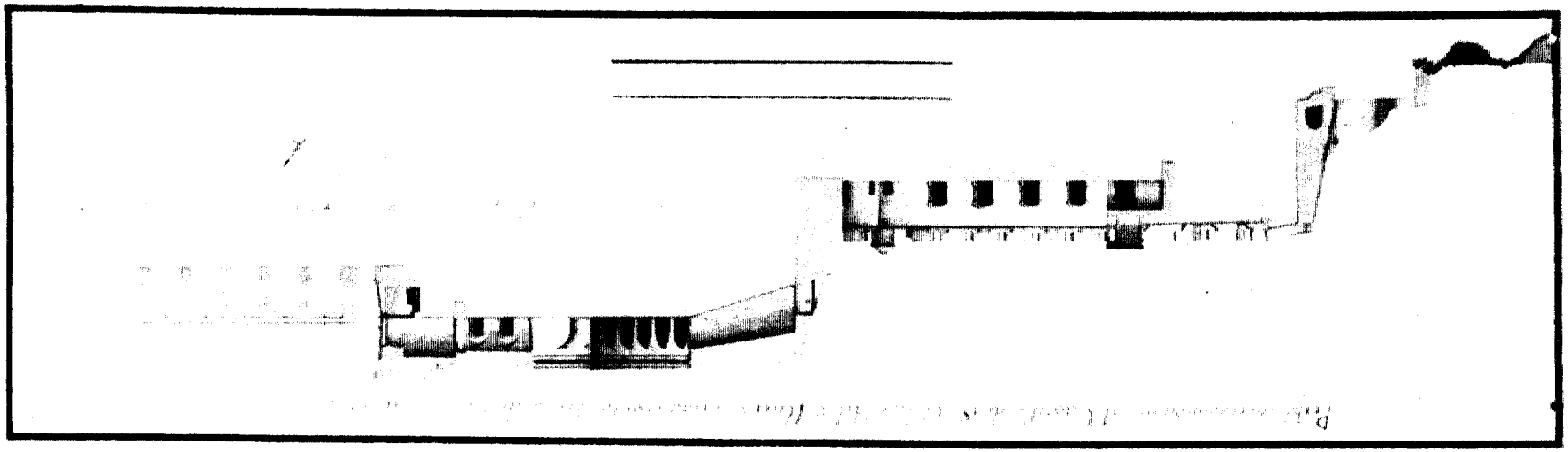
21. Existing conditions plan of el Morro and the southern city walls by Juan Mestre, May 12, 1787.

(following page)



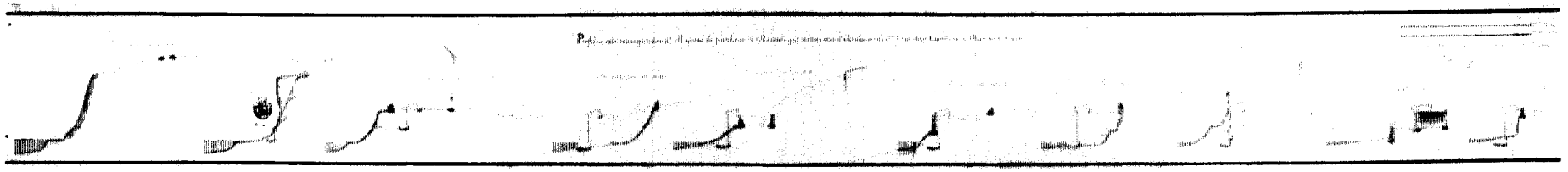
21a. Existing conditions section through el Morro by Juan Mestre, May 12, 1787.

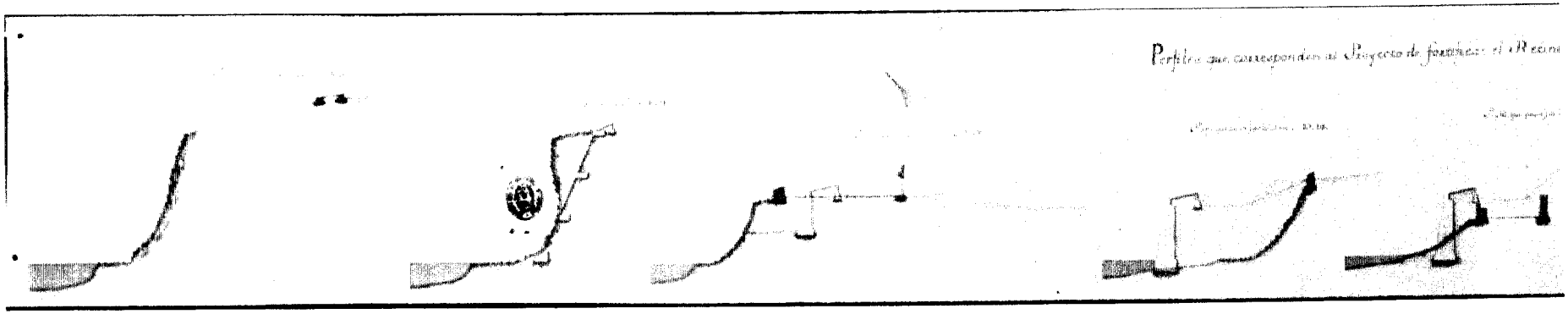
(following page)

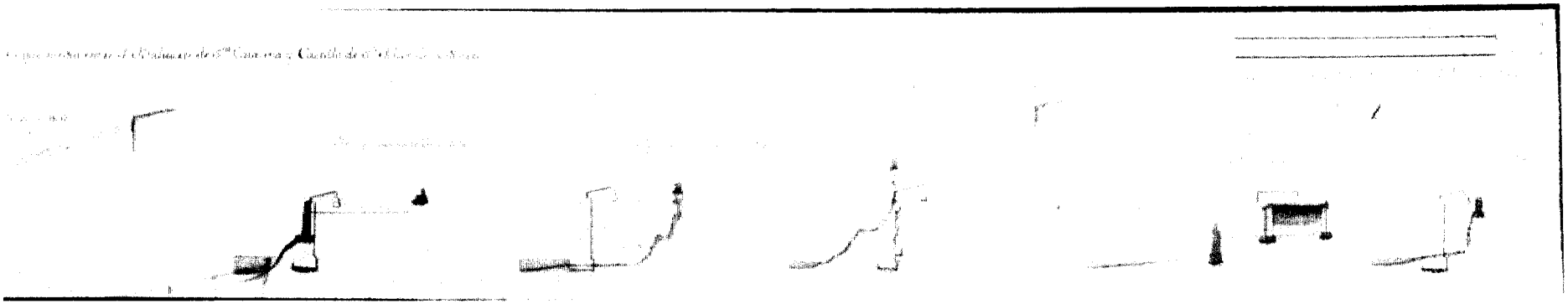


22. Section through el Morro by Juan Mestre, May 17, 1787. (Top: Whole section. Middle: Left side of section enlarged. Bottom: Right side of section enlarged.)

(following page)





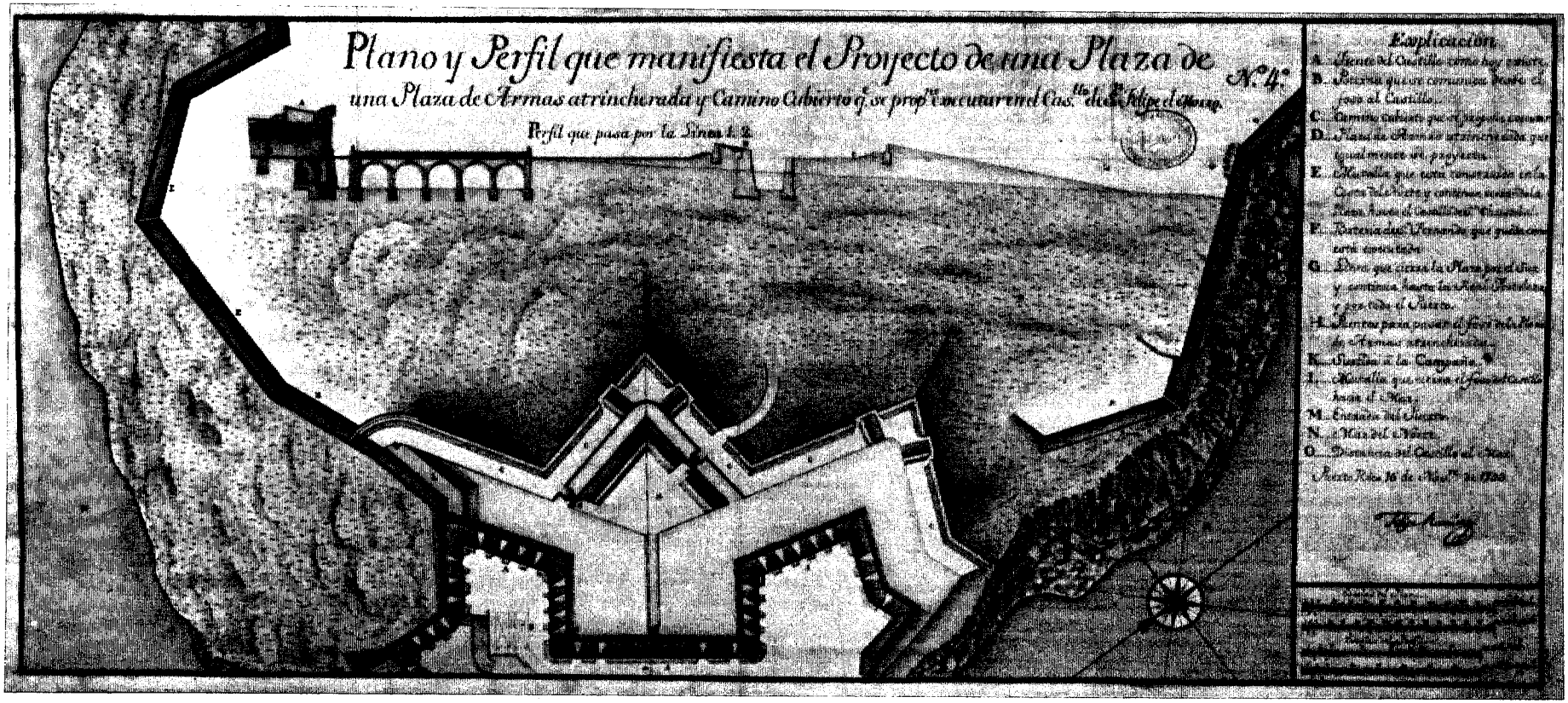


23. Plan of the City of San Juan by Juan Mestre, November 17, 1792.

(following page)

24. Plan and section of the plaza of el Morro by Felipe Ramírez, 1793.

(following page)


Plano y Perfil que manifiesta el Proyecto de una Plaza de
una Plaza de Armas atrincherada y Camino Cubierto q.e se prop.ne executar en el Cas.llo de S.n Felipe el Morro.
N.º 4.º
Perfil que pasa por la Linea 1. 2.
Explicacion
A. Frente del Castillo como hoy existe.
B. Poterna que se comunica desde el foso al Castillo.
C. Camino cubierto que se propone executar.
D. Plaza de Armas atrincherada que igualmente se proyecta.
E. Muralla que esta construida en la Costa del Norte y continua cerrando la Plaza hasta el Castillo de S.n Christobal.
F. Ratera de S.n Fernando que queda como esta executada.
G. Linea que cierra la Plaza por el Sur y continua hasta la Real Fortaleza y por todo el Puerto.
H. Puentes para pasar el foso de la Plaza de Armas atrincherada.
K. Sortida a la Campaña.
I. Muralla que cierra el foso del Castillo hasta el Mar.
M. Entrada del Puerto.
N. Mar del Norte.
O. Distancia del Castillo al Mar.
Puerto Rico 16 de Nov.re de 1800

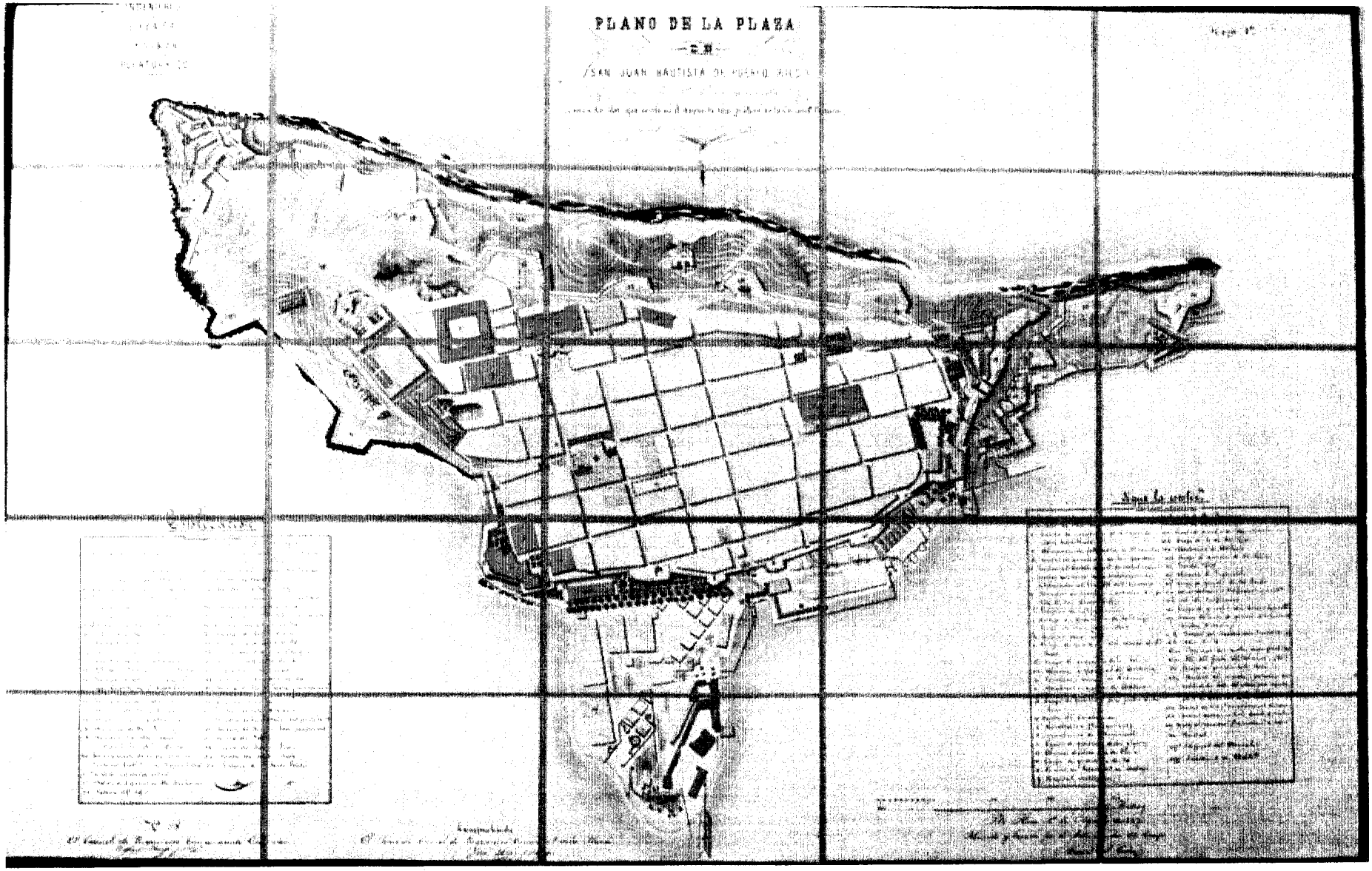
25. Plan of la Princesa by Felipe Ramírez, September 28, 1795.

(following page)

Perfil simple cortado sobre la linea 1.2.
Plano y Perfil del Fuerte nombrado la Princesa en la Plaza de S.n Juan de Puerto-Rico.
Explicacion
R....Rampa, que vaja à la Playa
O....Bateria de los quatro Obuses
AB..Porcion de Muro que no tiene Foso ni camino Cubierto.
C....Playa, y Rocas en donde tiene su arranque el expresado Muro.
Puerto-rico 28 de Sept.e de 1795.
Felipe Ramirez
Escala del Perfil
Escala del Plano

26. Plan of the City of San Juan by Rafael Clavijo y Pla, ca. 1852-1860.

(following page)


PLANO DE LA PLAZA
DE
SAN JUAN BAUTISTA DE PUERTO RICO

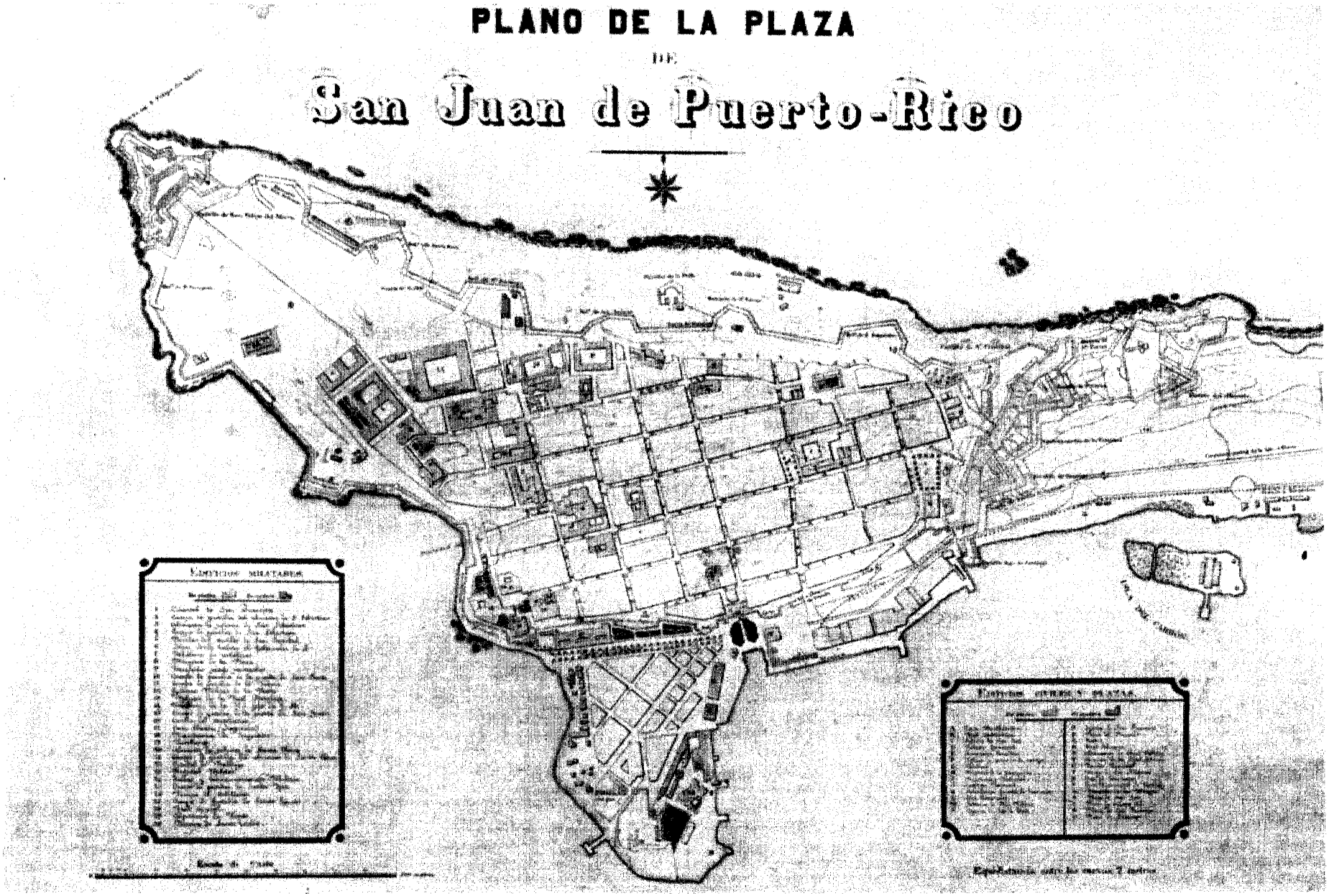
27. Plan of the City of San Juan by F. Roldán y Navarro, 1887.

(following page)

PLANO DE LA PLAZA

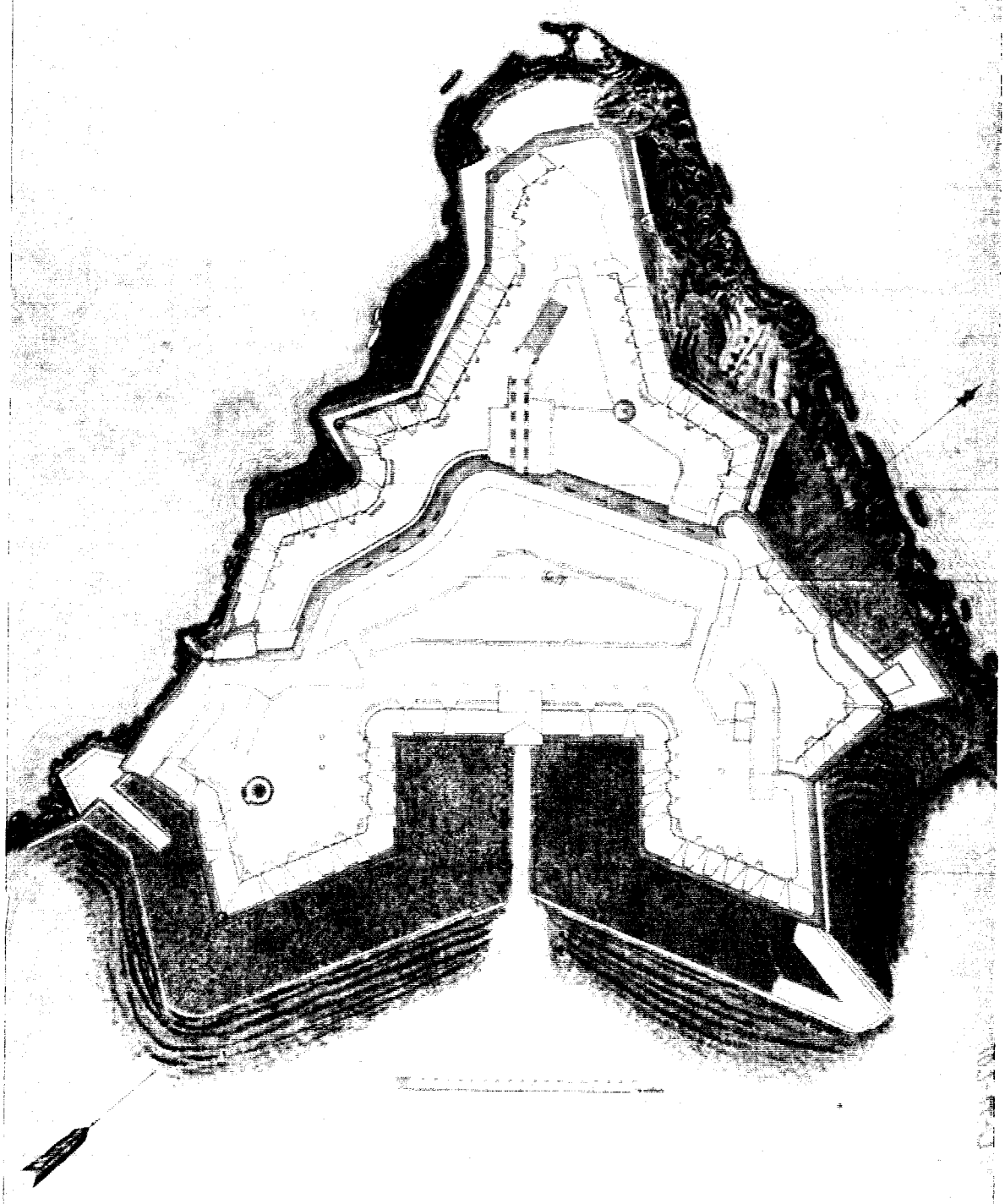
DE

San Juan de Puerto-Rico



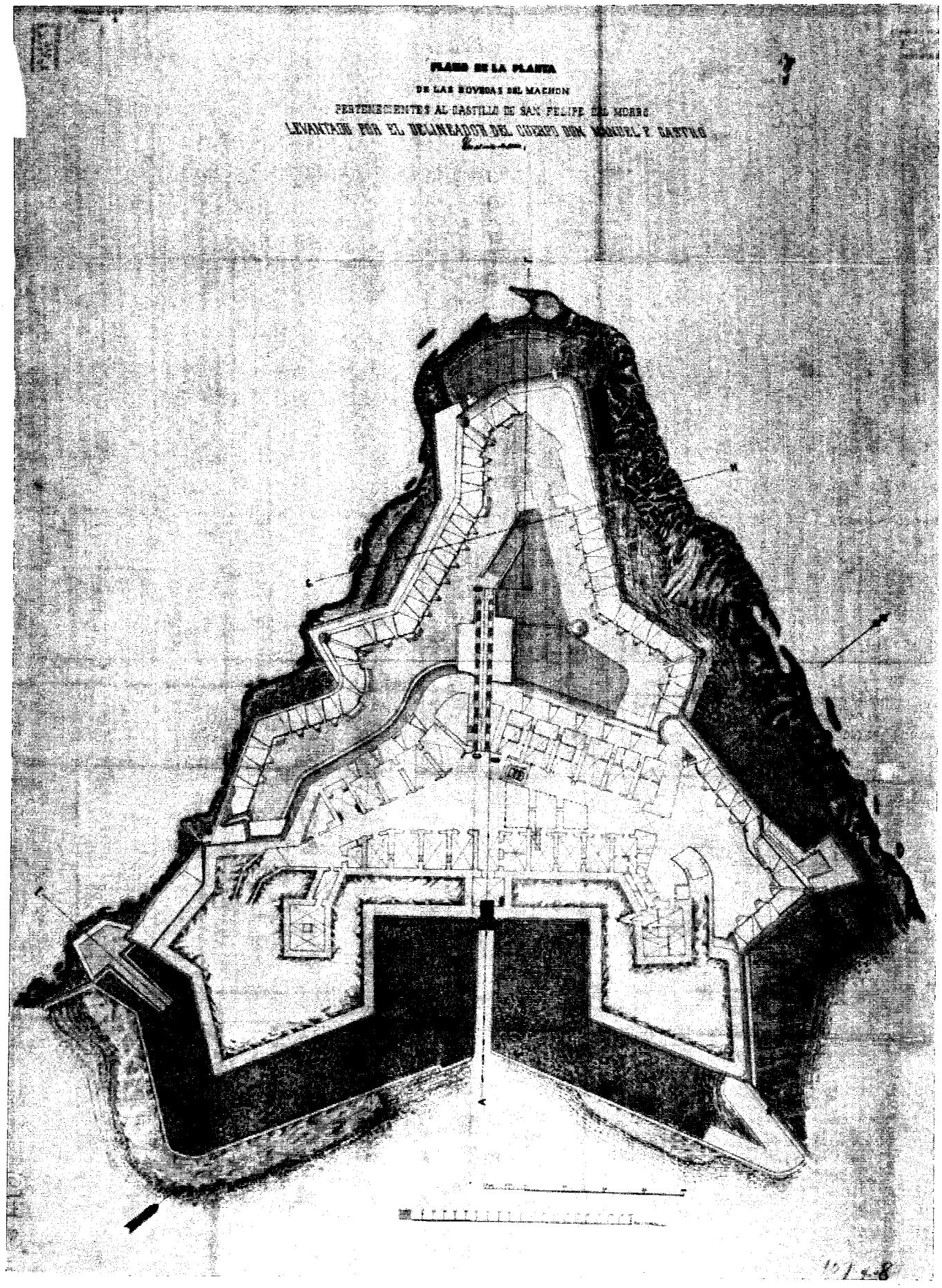
28. Roof plan of el Morro by Manuel Castro, 1861.

(following page)



29. First floor plan of el Morro by Manuel Castro, 1861.

(following page)

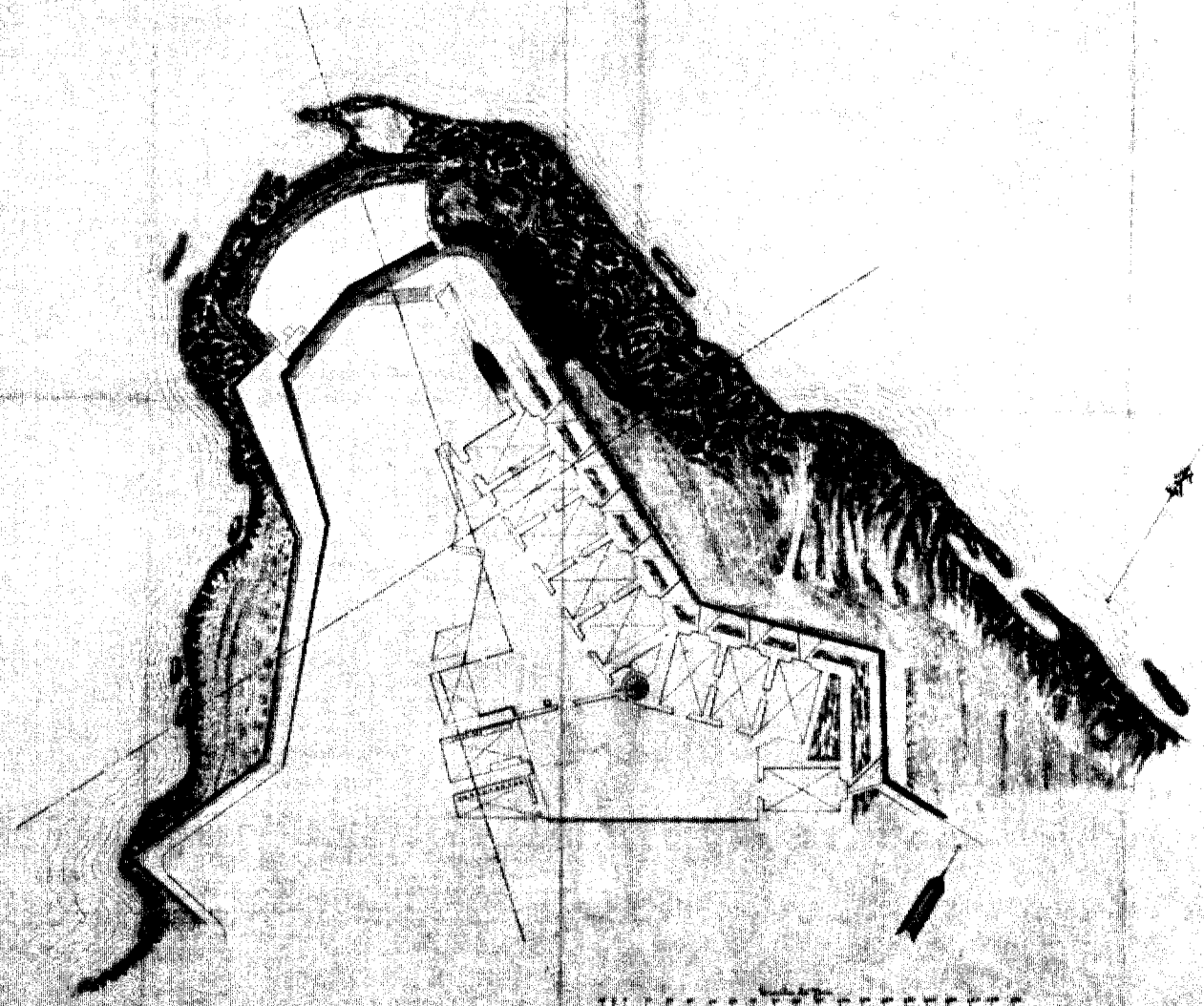

PLANO DE LA PLANTA
DE LAS BOVEDAS DEL MACHON
PERTENECIENTES AL CASTILLO DE SAN FELIPE DEL MORRO
LEVANTADO POR EL DELINEADOR DEL CUERPO DON MANUEL F. CASTRO

30. Detail of first floor plan of el Morro by Manuel Castro, 1861.

(following page)

PLANO DE LA PLANTA DE LAS BOVEDAS DEL PATIO BAJO PERTENECIENTES

AL CASTILLO DE SAN FELIPE DEL MORRO



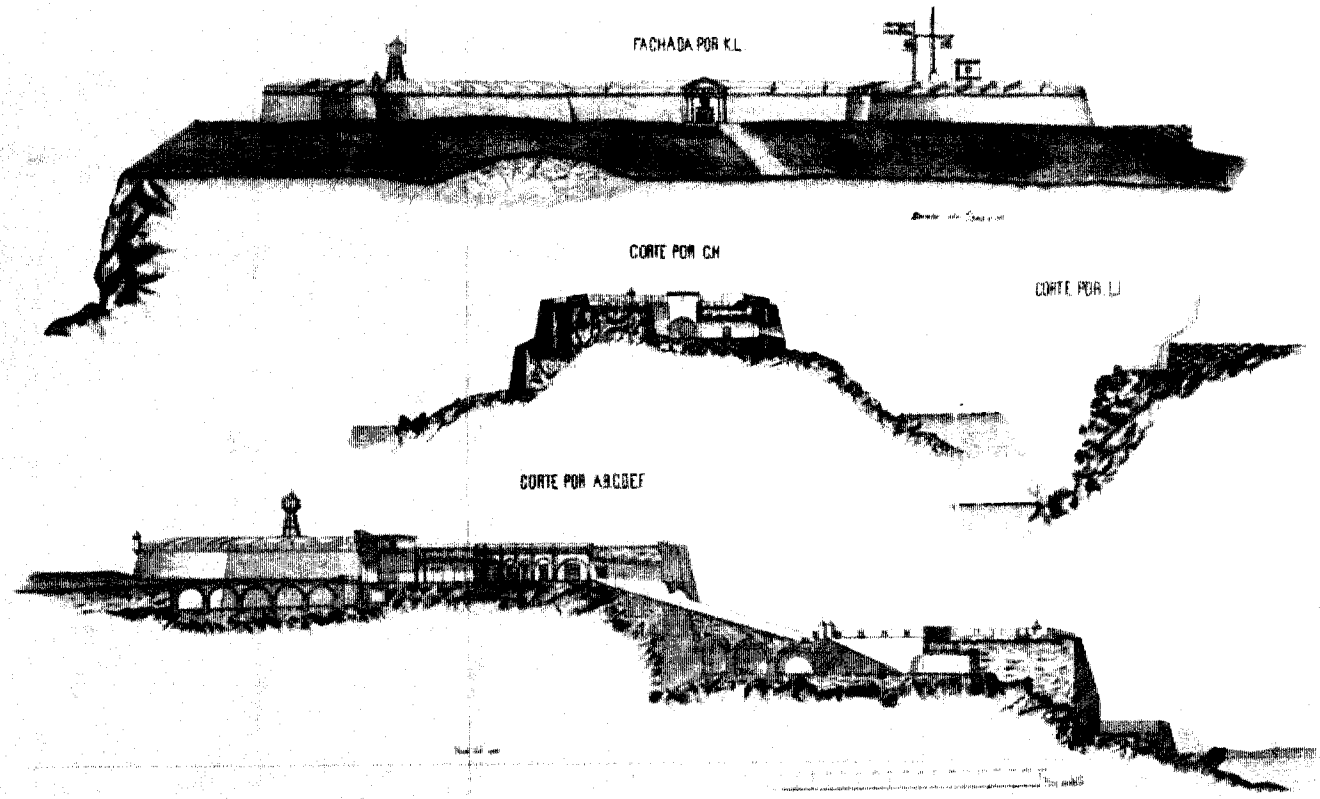
107-4-6

31. Elevations and sections of el Morro by Manuel Castro, 1861.

(following page)

PLANO DE LA VISTA Y PERFILES DEL CASTILLO DE SAN FELIPE DEL MORRO

LEVANTADO POR EL DELINEADOR DEL CUERPO DON MANUEL T. CASTRO EN EL AÑO DE 1880



32. Roof plan of San Cristóbal by Manuel Castro, 1861.

(following page)

INGENIEROS

PUERTO-RICO.

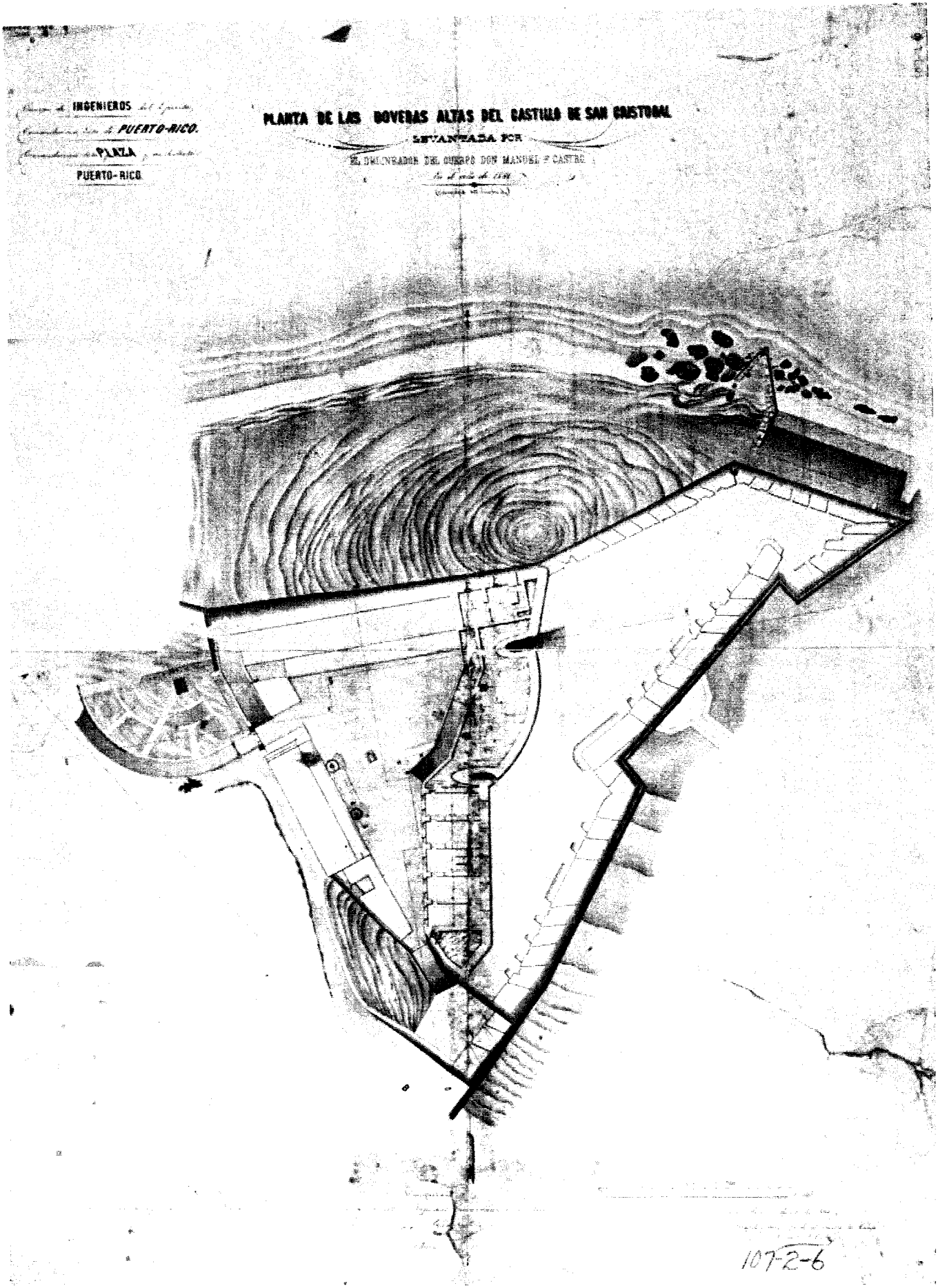
PLAZA

PUERTO-RICO.

PLANTA DE LAS BOVEDAS ALTAS DEL CASTILLO DE SAN CRISTOBAL

LEVANTADA POR

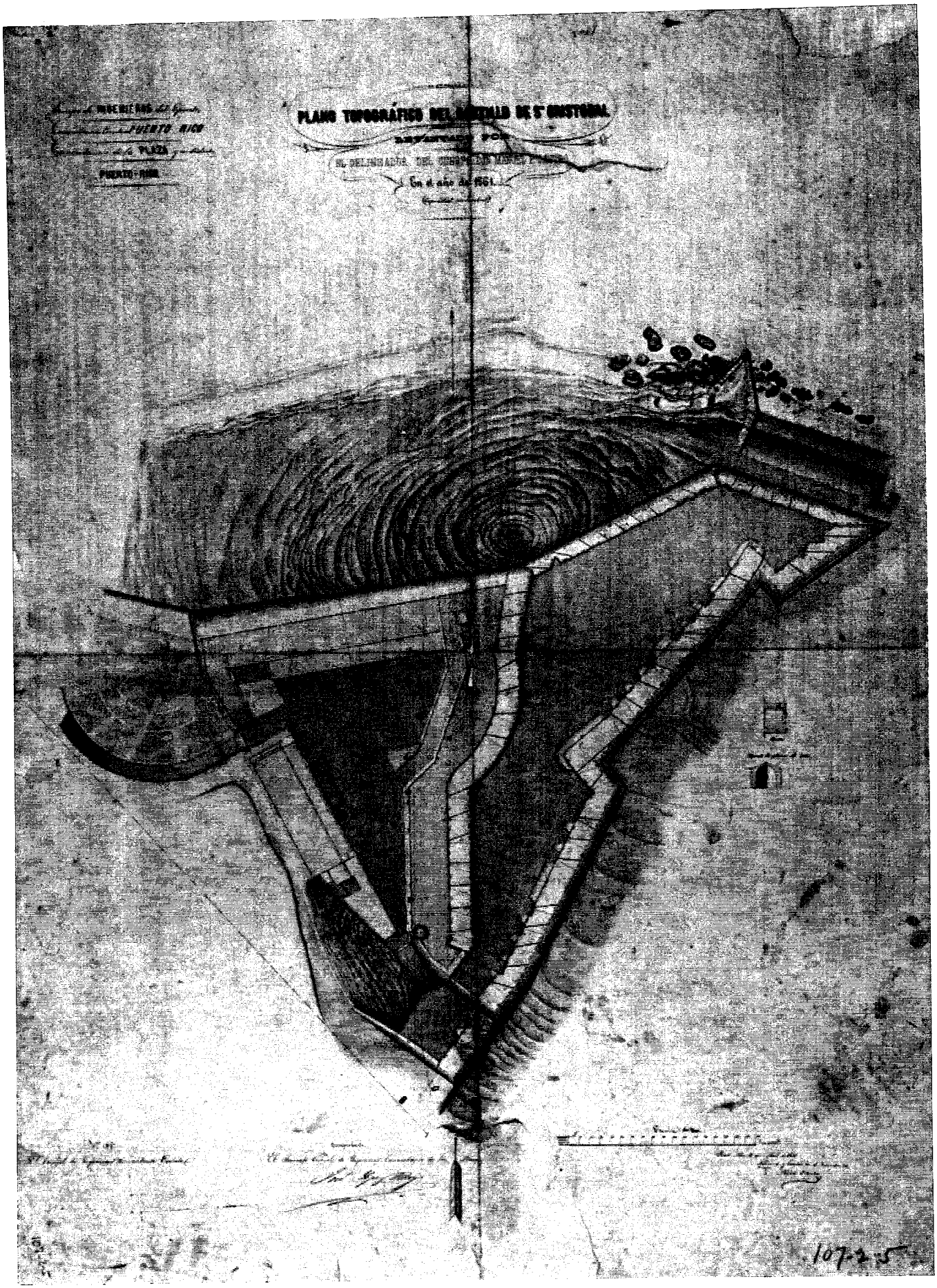
EL DELINEADOR DEL CUERPO DON MANUEL F CASTRO



107-2-6

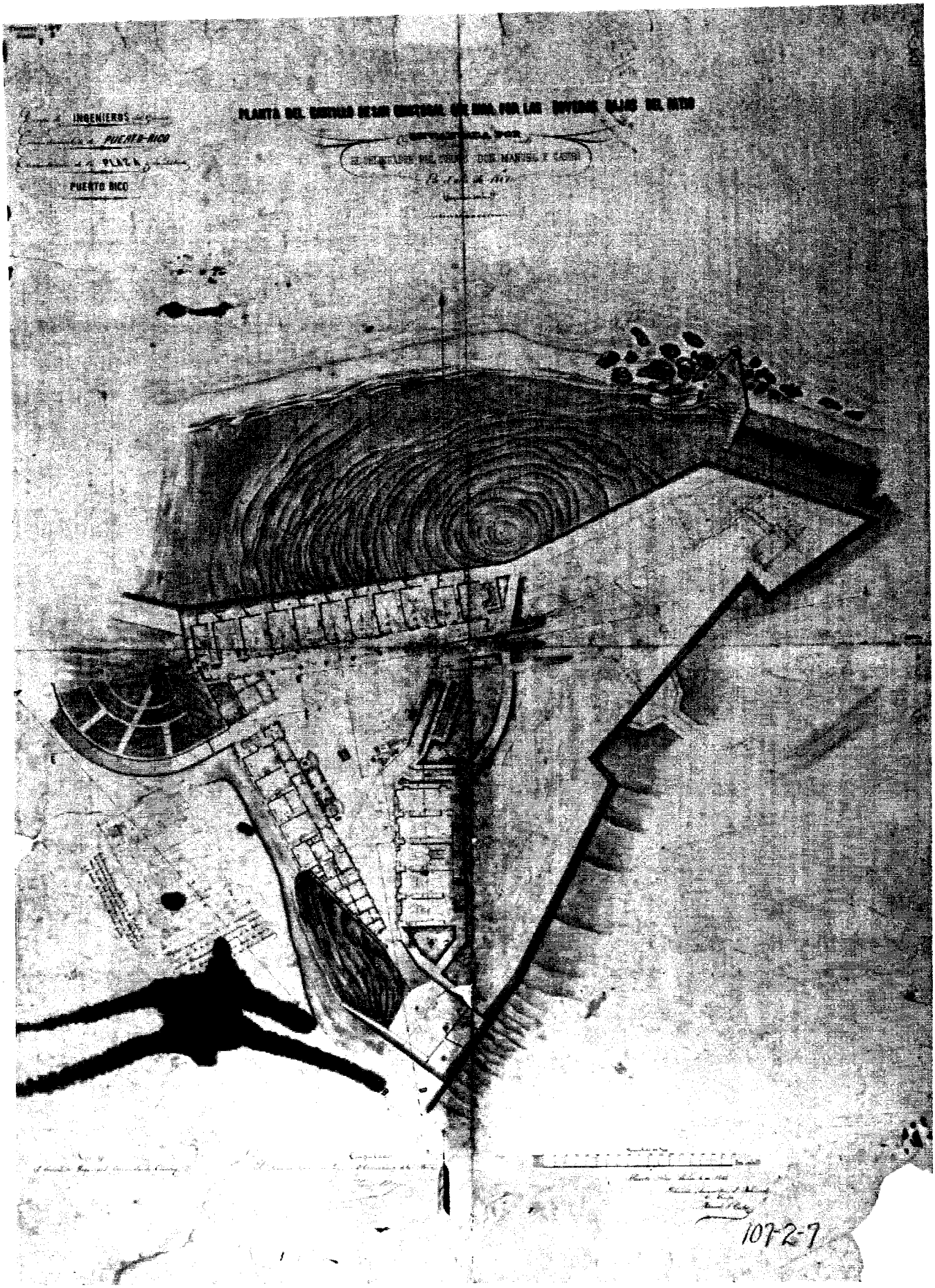
33. Second floor plan of San Cristóbal by Manuel Castro, 1861.

(following page)


PLANO TOPOGRÁFICO DEL CASTILLO DE S^T CRISTOBAL
PUERTO RICO
PUERTO-RICO
107-2-5

34. First floor plan of San Cristóbal by Manuel Castro, 1861.

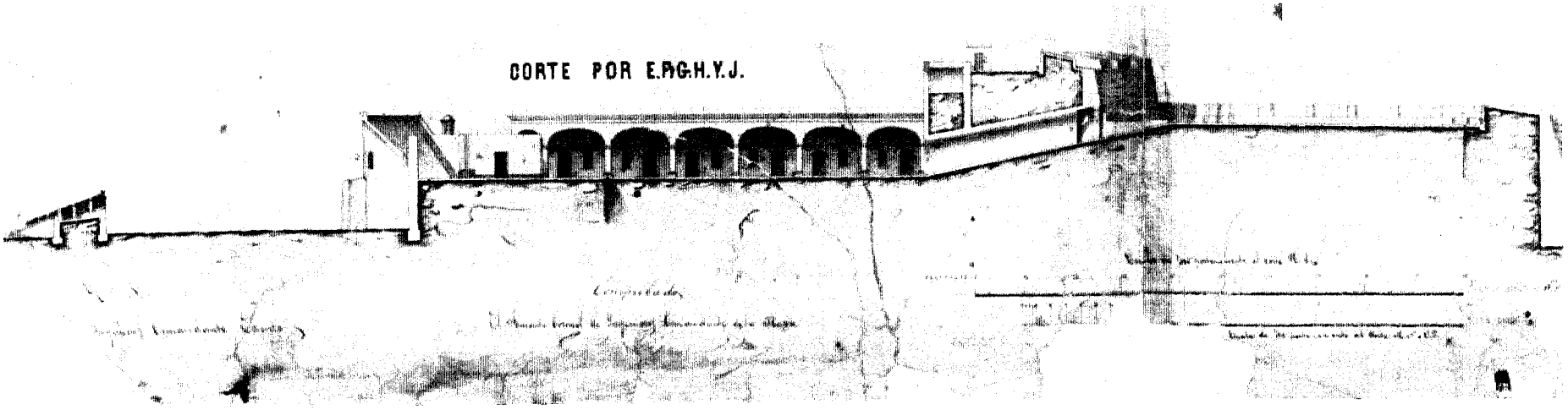
(following page)


INGENIEROS
PUERTO RICO
PUERTO RICO
107-2-7

35. West elevation of San Cristóbal by Manuel Castro, 1861.

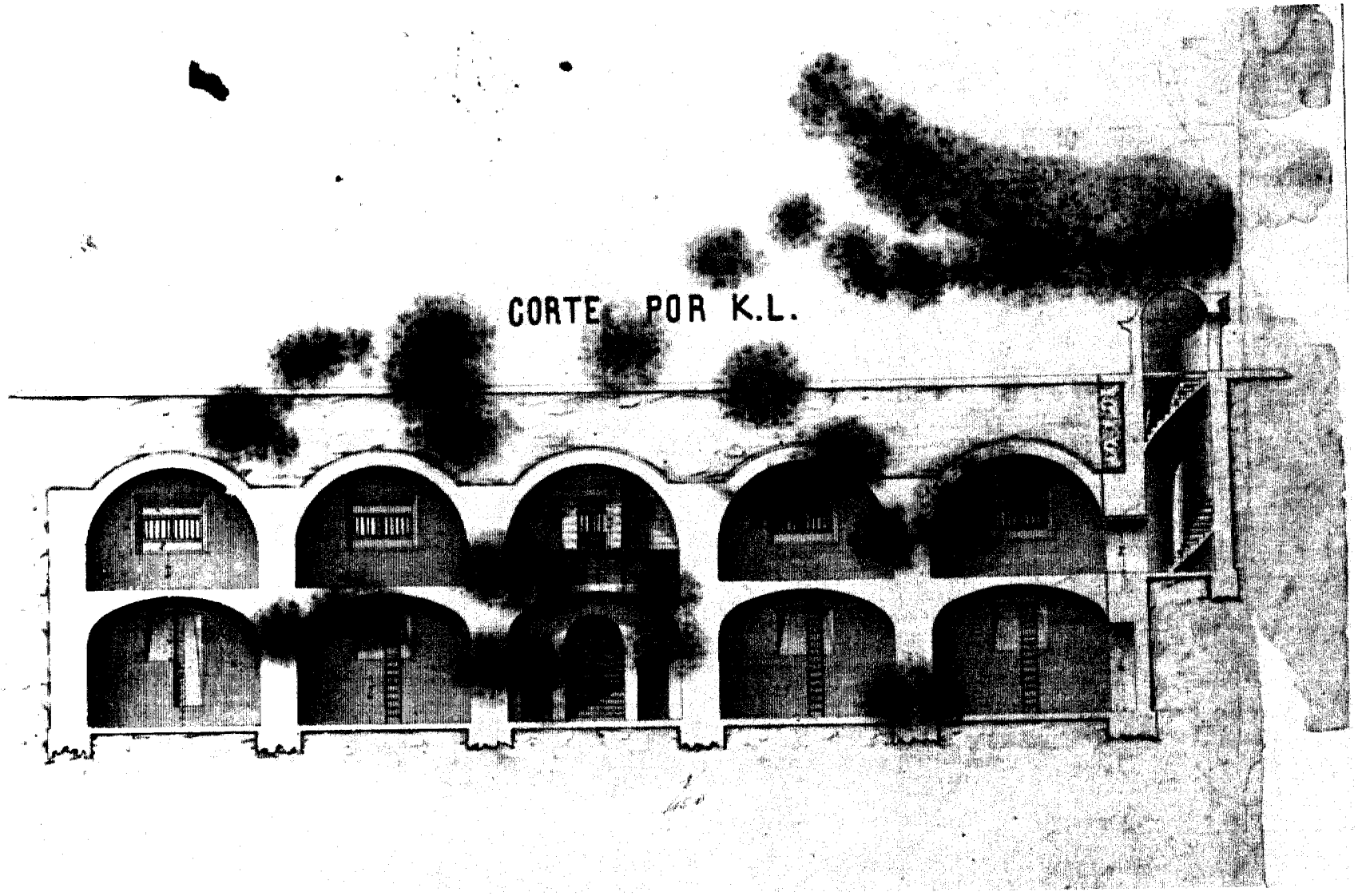
(following page)

CORTE POR E.F.G.H.Y.J.



36. Section through the Plaza de Armas showing elevation of the Troops' Quarters at San Cristóbal. Manuel Castro, 1861.

(following page)


CORTE POR K.L.

37. Section through the Plaza de Armas looking north and showing the North Casemates at San Cristóbal. Manuel Castro, 1861.

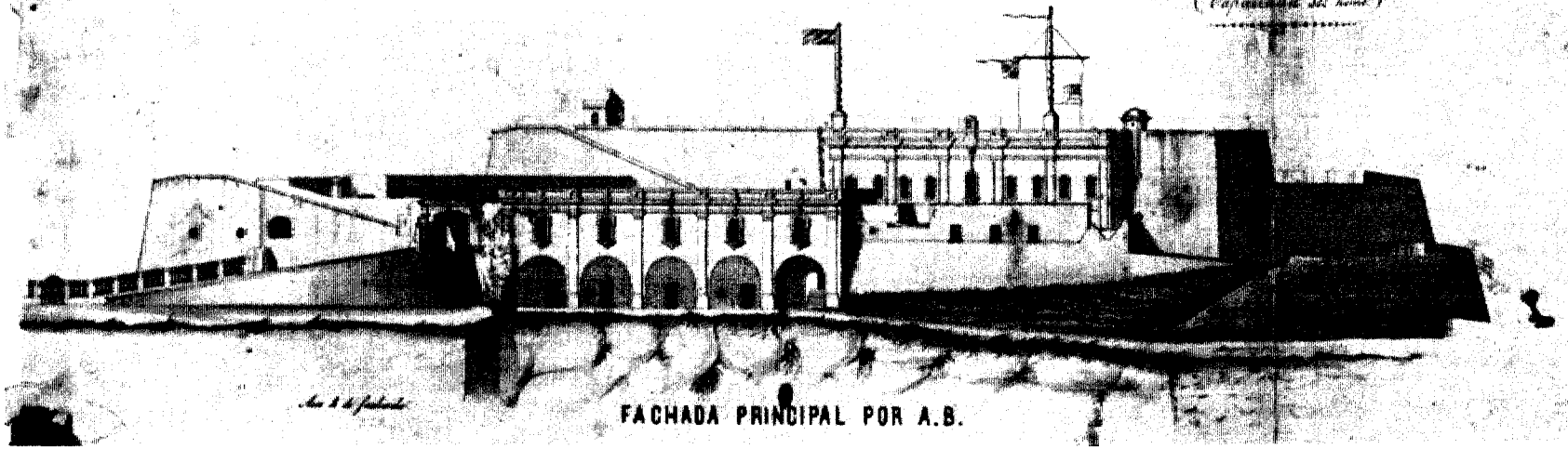
(following page)

Drawer 107
Sheet 2
B

Cuerpo de INGENIEROS del Ejército
Comandancia ESCUELA de Puerto Rico
Comandancia de la PLAZA y su distrito
PUERTO-RICO.

FACHADA Y CORTES DEL CASTILLO DE SAN CRISTOBAL

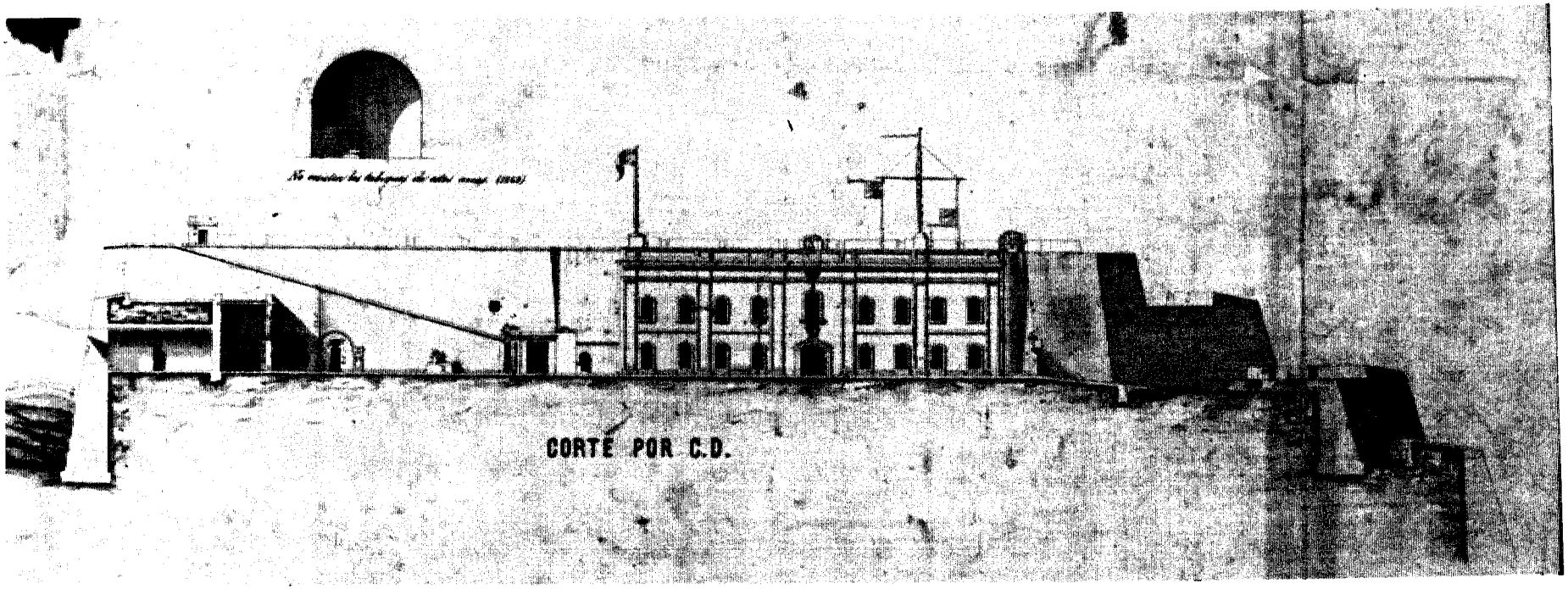
EL DELINEADOR DEL CUERPO DON MANUEL F. CASTRO
en el año de 1861.
(Capacidad 362 hombres)



FACHADA PRINCIPAL POR A.B.

38. Section through the Troops' Quarters looking east, San Cristóbal. Manuel Castro, 1861.

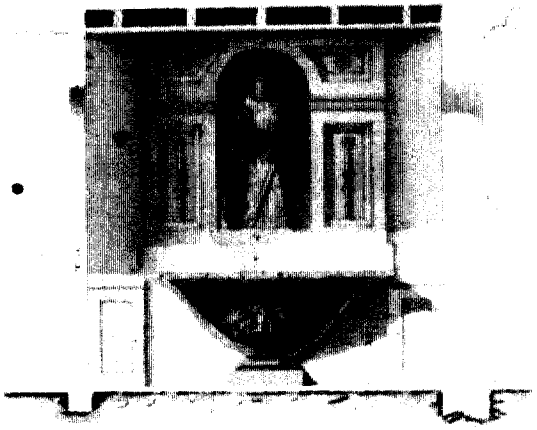
(following page)



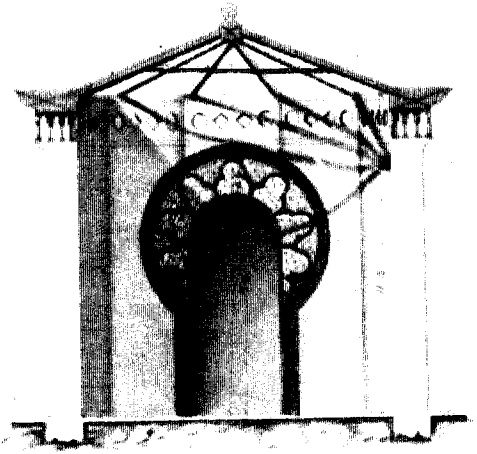
CORTE POR C.D.

39. Details of the Chapel and Well House on the Plaza de Armas of San Cristóbal. Votive statue believed to represent St. Barbara. Manuel Castro, 1861.

(following page)



CORTE POR M.N.



CORTE POR O.P.

APPENDICES

APPENDIX A.

El Morro Monument Lighthouse, San Juan, Puerto Rico: Examination of Conditions of Brickwork

MSSC *Masonry Stabilization Services Corporation*
755 Minnesota Avenue • P.O. Box 171677, Kansas City, KS 66117 • 913/281-2700 • Fax: 913/281-4385

EL MORRO MONUMENT LIGHTHOUSE

SAN JUAN, PUERTO RICO

EXAMINATION OF CONDITIONS OF BRICKWORK

Prepared by Frances Gale
Masonry Stabilization Services Corporation
for the
North Atlantic Historic Preservation Center
National Park Service

September 25, 1990

INTRODUCTION

At the request of the North Atlantic Historic Preservation Center (NAHPC) of the National Park Service, Masonry Stabilization Services Corporation (MSSC) inspected existing conditions of exterior masonry materials of the Lighthouse at El Morro Monument in San Juan, Puerto Rico. The inspection was conducted on May 17 and 18, 1990, with Blaine Cliver of the NAHPC. Materials were inspected from the ground level with the aid of binoculars. Representative samples of brick and mortar were taken for laboratory analyses.

The report below provides a description of exterior masonry conditions. The results of laboratory tests are summarized. (A report of this testing is attached.) Based on the observations made during the inspection and on the test results, probable causes of deterioration are identified. Stabilization measures are discussed.

CONDITIONS

Lower portions of the Lighthouse at El Morro, constructed in 1867, are brick with a lime based mortar. Both materials are in relatively good condition.

The upper portion of the Lighthouse, which was rebuilt in 1906, appears to have a harder, portland cement based mortar. There is a dramatic difference between conditions of the 1867 portion of the structure and those of the 1906 portion. Brick in most of the upper portion is affected by moderate to very severe deterioration. In some locations, there are losses of entire bricks. There appears to be a pattern of deterioration in this area: erosion is most severe along the outer edges of each brick and the centers are relatively intact. The generally good condition of the 1906 mortar makes this pattern particularly noticeable.

Efflorescence was not visible in either the 1867 or the 1906 portion of the structure.

TESTING

Laboratory testing was undertaken to determine the cause (or causes) of the advanced deterioration of brick of the 1906 portion of the Lighthouse where a portland cement based mortar was used. Here, deterioration appears be related to the preferential movement of moisture and dissolved salts through the more porous brick.

Although there were no visible signs of efflorescence, the presence of soluble chloride salts within the masonry seemed likely because of the seaside location of the Lighthouse. Samples of red brick and of portland cement based mortar from the 1906 portion of the structure were removed for laboratory testing. Analyses were conducted on both exposed and interior faces of the samples. On the brick sample, the chloride level was more concentrated on the exposed face (515 ppm) than on the interior face (455 ppm). On the mortar sample, the chloride level was more concentrated on the interior face (515 ppm) than on the exposed face (333 ppm).

These data suggest that the migration of soluble chloride salts which accompanies evaporation of water from the masonry materials proceeds more rapidly in the brick than in the portland cement based mortar.

It is well known that hard, comparatively nonabsorbent portland cement based mortar is detrimental to soft brick. In fact, according to one source, "many cases of decay have been directly traceable to the porous (brick) being pointed with impervious mortar. In such cases, both saturation and evaporation are confined to the (brick) whereas the process should be evenly distributed over stone and pointing."[1] It is thought that the difference in density of the bricks and the mortar is directly proportional to the degree and rate of weathering of the brick. Additional testing, which will include evaporation studies, is being conducted by the NAHPC to confirm the role of portland cement mortar in the advanced deterioration of brick of the 1906 portion of the Lighthouse.

RECOMMENDATIONS

An understanding of the causes of deterioration of the brickwork of the Lighthouse is a prerequisite to determining appropriate measures to stabilize deterioration. The advanced degree of deterioration of the brickwork, however, suggests that a repair material will be necessary to stabilize the upper portions where considerable material has been lost. A survey of possible repair materials was preliminarily made. As with any restoration work on any historic structure, compatibility of the repair material with the brick was an important consideration. In addition, its resistance to deterioration caused by soluble salts was essential.

A repair material that appears to be appropriate for this project is Jahn M100 Terra cotta/brick Restoration Mortar available through Cathedral Stone Company in Washington, D.C. M100 is a cement based mortar that was developed for <u>in situ</u> repair of terra cotta and brick. The hardened M100 reportedly remains porous to water vapor and soluble salts and has been successfully used in areas where salt contamination is a problem. Also

claimed is the ability to adjust mechanical and physical properties of M100 to better match those of the substrate. Product literature describing M100 is attached.

Preliminary examination of M100 was made in the laboratory to determine its condition following exposure to a solution of sodium chloride. A sample of hardened M100 was immersed in a 15% solution for 21 days. Weight gain was measured at approximately 25% of the original weight of the sample. Following drying, the sample was examined for adverse effects. No visible deterioration or efflorescence was seen.

It is recommended that the use of Jahn M100 Terra cotta/brick Restoration Mortar be evaluated at the job site. Working with the manufacturer, mechanical and physical properties of M100 should be adjusted for optimum compatibility with existing brick and mortar materials. It may also be advisable to apply a coating to all brickwork for additional protection and to provide visual continuity of the wall.

[1] Harley J. McKee, Introduction to Early American Masonry (Washington: National Trust for Historic Preservation, 1773), pp 72-73.

LABORATORY REPORT

ProSoCo, Inc.
P.O. Box 171677
Kansas City, Kansas 66117
Phone 913/281-2700

FOR: Fran Gale

DATE: June 21, 1990
PROJECT: 9005-28 SA

SUBJECT: El Morro
San Juan, Puerto Rico
Anionic Salt Analysis

SAMPLES SUBMITTED: One existing, red brick fragment.
Size: 1 1/2" x 1 1/2" x 3"

Three existing, buff mortar fragments.
Size: largest - 7/8" x 1 1/2" x 2 1/2"

Submitted by: Fran Gale

==========

PURPOSE OF TEST:

To determine the chloride ion content at the exposed and interior surface of submitted samples.

==========

TEST METHODS:

Anionic Salt Analyses:
Chlorides - Drop Count Titration Method

Two grams from the exposed face and interior are pulverized, mixed with distilled water, and boiled for one hour. After allowing the solution to cool, the sample is centrifuged until the precipitate separates. The resulting supernatant containing solubilized salts is used for testing.

Chlorides - The supernatant is allowed to react with a silver nitrate solution. The chloride level in ppm is calculated from an evaluation of reaction rate.

==========

TEST RESULTS:

Anionic Salt Analysis: Chlorides

Existing, Red Brick Fragment

Exposed Face	Interior Face
515 ppm	455 ppm

TEST RESULTS: (continued)

Existing, Buff Mortar Fragment	
Exposed Face	Interior Face
333 ppm	515 ppm

CONCLUSIONS:

The test data indicates that chloride ions are present throughout the entire brick and mortar samples. In the brick samples, chlorides are more concentrated near the exposed surface (515 ppm) compared to the interior (455 ppm).

In the mortar samples the salts are more concentrated near the interior surface (515 ppm) compared to 335 ppm for the exterior samples.

Jack Sykes
Masonry Testing Specialist

JS/vs

All recommendations made within this report are based on laboratory test applications and observations. Fi
determination of the suitability of a product and/or procedure should be made only after thorough job testing
actual surfaces.

APPENDIX B.

Structural Inspection of Castillo de San Cristobal, San Juan, Puerto Rico

[illegible]
[illegible]
Bureau of Reclamation

INFORMATIONAL ROUTING

D-1512
Rutenbeck

OCT 6 1989

D-1512

Memorandum

To: National Park Service, Southeast Cultural Resources Preservation Center, 1835 Northridge Road, Dunwoody, Georgia 30338

From: Chief, Division of Research and Laboratory Services

Subject: Structural Inspection of Castillo de San Cristobal

Enclosed is a summary report of Todd Rutenbeck's recent inspection of Castillo de San Cristobal in San Juan, Puerto Rico.

We believe this report will be very helpful to you in your preservation work. As our workload permits, we will be happy to assist you in any future inspections of this nature.

Enclosure

Copy to: Regional Director, Southeast Region, National Park Service, 75 Spring Street S.W., Atlanta, Georgia 30303
Superintendent, San Juan National Historic Site, PO Box 712, Old San Juan, Puerto Rico 00902
(with enclosure)

Blind to: D-1510
D-1512
D-1512 (Rutenbeck)
(with enclosure)

JSPierce:ked 15/12

STRUCTURAL INSPECTION OF CASTILLO DE SAN CRISTOBAL SAN JUAN, PUERTO RICO

by

Todd Rutenbeck, Civil Engineer
October 1, 1986

This report summarizes my evaluation of Castillo de San Cristobal, made during my July 20-25, 1986, visit to the site. The purpose of the visit was to locate major structural defects and plan any needed structural monitoring instrumentation.

There are three areas at Castillo de San Cristobal where structural monitoring instrumentation should be installed to determine the current rate of movement and the potential for structural failure. Four cracks in the Dungeon are currently being monitored with telltale gauges with an accuracy of about 0.5 mm. Waterproof dial gauges with an accuracy of 0.01 mm should be installed and read monthly. One and possibly two dial gauges should be installed on the cracking at the Dungeon entrance. In addition to the Dungeon, the Chapel and the Officers' Quarters should be instrumented. Both contain numerous structural cracks. One dial gauge should be placed on each structure on one of the widest cracks. The Chapel gauge could be located on the corner nearest the plaza on an interior crack near the top where the gauge would be partially hidden from view. On the Officers' Quarters, the gauge could be on the far end of the building just below the roofline.

With the exception of the above areas, the Castillo shows few signs of major structural movement that would warrant instrumentation. Some vertical cracks exist in the massive walls, but even if several inches of movement occurred, there would be no danger of structural collapse. There are also cracks along the top of the fortifications that are parallel to the outer masonry wall face and may coincide with the interface of the rubble interior and the outer stone work. These cracks are narrow, and because of the slope of the wall pose no danger of structural failure even if the cracks become several times wider than they are now. Neither crack type now warrants instrumentation. Neither currently threatens structural integrity. In some cases, it may be desirable to seal such cracks against moisture.

While the structural condition of Castillo de San Cristobal is generally good, there are numerous areas where localized deterioration or moisture problems threaten the structures. These occur in the plaza area and cisterns, the outworks, in walls along the oceanside, the tunnels, and the Dungeon.

The entire plaza area needs to be investigated. The numerous cracks in the Chapel indicate possible foundation or moisture problems. Underground water, sewer, or storm drain pipes need to be located and checked for leaking. If instrumentation indicates the Chapel cracks are still widening, it may be necessary to remove plaster and masonry near the cracked areas to explore the interior. It would also be necessary to remove part of the plaza concrete slabs near the foundation of the Chapel to explore the foundation and moisture sources. Similar investigations may be needed near the Officers' Quarters which contain numerous cracks. Most cracking is on the two end additions to the structure which may be on weaker foundations than the central part which is above the cisterns. Water drainage from the roof of the Officers' Quarters needs to be traced. Much of the roof is composed of weathered brick with no waterproof surface. It could act as a giant sponge that would hold rainwater. A small area of the roof should be excavated between two arches to see the depth of moisture penetration and the internal condition of the building. Runoff from the roof should also be traced. The condition of the downspouts and final destination of the water needs to be determined. The purpose of tracing the water is to determine its effect on the building, its foundation, and the cisterns below. Reinforced concrete structures in the plaza area need to be watched closely for cracking due to reinforcing steel corrosion.

While the cisterns appear to be in good structural condition, they contain large deposits including stalactites and stalagmites. The large volume of deposits causes concern for the source of the leached material. If all of the material originated in the lime mortar used to construct the cistern vaults, these structures may have lost considerable structural strength. Finding the source of water flow and the source of leached material should be included in the investigation of the plaza area. Possible sources of the deposits include lime mortar, portland cement concrete and mortar, soil, and water with dissolved minerals leaking from waterlines. Rainwater should be mineral-free, but would readily leach minerals from construction materials and soils before reaching the cisterns. Excavating from the top to the outside of a vault near an area of heavy deposits would assist in tracing water flow. It would also allow inspection of the vault and a determination of brick and mortar strength in the inflow area. It may be necessary to change waterflow patterns and to repair any structural damage. Modern and historic drains should be traced. The level of water in the center cistern and its effect on the adjacent cisterns should be determined.

In the outworks, the unlined tunnel section is slowly collapsing. If there are no plans to support and line this section, it should be inspected annually to determine when the collapse may progress to affect the ground surface above. The brick-lined tunnel sections in the outworks (and elsewhere in San Cristobal) have numerous joints between bricks that are not completely filled with mortar. It appears that this occurred in original construction and is not due to deterioration. Only bricks that are loose or in danger of falling should be repointed. There are several areas in the outworks where there is coving (erosion) near the base of the fortification walls that eventually could worsen and lead to settlement. These areas should be repaired and ground surfaces should be regraded to make surface water run away from the walls. The outer part of the concrete ring of the 1890's gun emplacement has also been undermined by erosion. The eroded areas need to be excavated, provided with a foundation, and filled to provide structural support. Some buildings in the outworks also need erosion repairs and regrading of soil.

There are numerous areas of deterioration and erosion along the oceanside of Castillo de San Cristobal and its outworks. The lower concrete seawall below La Princesa Bastion is in generally good condition, but it is being undercut by wave action that could eventually result in foundation failure. The undercut areas need to be filled with concrete. Existing small stones and riprap are grinding the foundation away when they are moved by turbulent water. Perhaps new and larger riprap should be considered.

The entire cliff and wall complex from La Princesa Bastion to the Haunted Sentry Box needs to be inspected by technical climbers working from ropes to locate areas of undercutting, stone and mortar deterioration, and structural stability problems. From below it appears that there could be many areas requiring repair. The masonry wall below La Princesa Bastion may have localized deterioration. The diagonal wall joining this wall near the top has deterioration (possibly due to water leaching) along its base and needs to be inspected by climbers. Much of the mortar that is near the ocean appears to be white and very weak, and could be suffering from salt action. The upper, more vertical wall section between La Princesa and Santa Teresa Bastions appears to be badly in need of repointing to prevent individual stones from falling. Climbers could confirm the extent of this problem. The original sandstone block walls at ocean level have lost mortar and stone. The holes should be filled and the joints repointed. There is a drain trough in the cliff wall that has lost mortar and contains heavy vegetation. The vegetation should be removed and the stone must be repointed to prevent settlement. The fortification wall located above the Haunted Sentry Box is badly undercut with a large area of soil and stone missing. A sound foundation must be established and the section must be rebuilt to support the wall above.

There are currently no signs of massive movement of structures along the ocean cliffs. There are, however, many signs of localized deterioration that could lead to bigger structural problems. In addition to problems discussed above, there are numerous areas where plant growth may be causing or hiding structural deterioration. These range from small plants and hanging gardens to large trees. While plant growth can be tolerated in some areas, in most cases it will have to be removed to make effective repairs and to prevent future damage. It would be helpful to make trial repairs under the direction of the Southeast Cultural Resources Preservation Center to determine the best way to deal with plant growth. Even after removing plants, filling holes, and repointing, frequent maintenance may be necessary.

The Dungeon may pose a hazard to the public. The planned structural monitoring should indicate if there are movements that could lead to structural collapse. Of more immediate concern is the possibility of rockfall that could injure visitors. Such occurrences would be instantaneous and could not be predicted by structural monitoring. In the area beyond the barricade numerous rock fragments had fallen to the floor with the largest being fist-sized. It is likely that similar rock fragments have fallen in the rest of the Dungeon but were removed in cleaning the portion open to the public. As a minimum precaution, the entire crown and walls of the Dungeon tunnel should be inspected from a stepladder. Rock that can be removed without the use of tools should be taken down. This inspection will help determine if further inspections by tunneling experts or mine safety officials is needed. Park records should be checked for indications of frequency of rockfall or any injuries from rockfall.

Todd Rutenbeck

APPENDIX C.

Preliminary Petrographic Analysis of Selected Masonry Sample from San Cristóbal

F O R D H A M U N I V E R S I T Y Bronx, N.Y. 10458

Department of Sociology and Anthropology

DRAFT

March 9, 1987

Dear Frank,

For a first quick run through, it seems like the principal temper or aggregate comes from a granitic source. Quartz definitely predominates, and a tendency toward grain rounding--with much variability, though--makes me think beach or estuary. There are occasional examples of feldspar, mostly single direction twinning so I'd guess Na/K species, but one or two fragments of plagioclase twinning were visible, never very well developed. Further speculation: acid igneous source. Ferromagnesians are rare, which together with the rarity of feldspars would be expected for a well worked sediment. Fe/Mg minerals appear to be largely hornblende and a mica (probably biotite), and a still unidentified high-order mineral with no apparent cleavage. A look at the geological reports will help here.

There is also a lot of biological calcite, sometimes pieces of larger mollusca. I don't know the species, so I couldn't assure you that they come from beach deposits of recent date, or ancient fossils from some long-deposited sediment. I suspect the former.

At first look, it did not look like there was much embedded ceramic. But I was very tired yesterday, and by day's end I was seeing close to double, so this point should be clarified later.

Sincerely,

Allan S. Gilbert

DRAFT

Petrographic Thin Sections

SAJU 2 - San Carlos - middle casement, S. window, original (1) construction mortar. 1773.

SAJU 3 - San Cristobal - Dungeon Vault mortar - impressions in (1) formwork. Pre O'Daly. (pre-1764/5)

SAJU 4 - Sta Teresa. c 1897. Guard House Stucco. (2)

SAJU 5 - La trinidad, Ramp paving 3. (3)

07m006B - Officers Quarters. c1775. Cistern I. Red hydraulic (3) stucco from ceiling.

07P015 - Pre arch infill stuccos - Officers Quarters Pier 4. (2)

07 P037 - Officers Quarters. Interior Partition wall material, (2) CM 3a. c 1861.

01m007 - Ramp. Bedding mortar of impost block of arch 1, 1775-80. (1) % agg 36 / % fines 3 / % Acid Sols 61.

10m047 - North Bastion. c 1780's, Terreplein pavement under (1) early brick. % agg. 67 / % fines 11 / % Acid Sols 22.

13m008 - Exterior Stucco of Lightning tower, 1818. San Carlos. (1)

19m038 - Stone Bedding mortar of Banquette. c 1861. (1)

19c' - San Carlos. Middle Casement, North window, #4, arch infill. (1)

SAJU 2 - mostly angular to subangular quartz, orientation tending toward vertical axis (or section is over thin) also particals of sodium potassium NaK feldspars with single twinning plains; grain size medium (will calibrate later). Accessary minerals rare, probably presence of hornblende and mica, probably biotite. Occassional large pieces of secondary carbonate but absence of biological carbonates, fairly porous.

SAJU 3 - Small to medium quartz, angular to subangular, axis tending toward horizontal (or slide slightly thick) much biological carbonate including complete nannoplanktens, Nondiscript calcareous agglomerations may be secondary calcite, Much free hematite Small amounts of hornblende. Twinned feldspars apparently absent.

SAJU 4_1 - Large rounded quartz grains, very porous with secondary calcite but some evidence of biological calcite (broken pieces of large creatures).

SAJU 4_2 - Ditto.

SAJU 5_1 - Small to medium quartz grains, mostly angular some subangular, blobs of secondary calcite, hornblende and biotite very rare and small. Fairly porous, much free hematite and no biological calcite. No twinned feldspars.

SAJU 5_2 - Quartz particals highly mixed sizes. Big ones tend to be subround to round and small ones are angular. Much fine iron pigment, submicroscopic, in the matrix. No immediately detectable accessory minerals.

SAJU 5_3 - Small to medium quartz, subangular to subround, some secondary calcite, some small accessary mica, biotite, hornblende presence rare. Free hematite is fine grained. No apparent twinned feldspars.

01M007 - Medium to large quartz, mostly subangular, biological calcite is common. Matrix somewhat porous. Unidentified accessory very rare -- high birefringence.
Also rare globs of hematite.

10M017 - # Quite dense aggregate, mostly subangular to subrounded quartz. Biological calcite present, possible grog (granuals of lighter colored previously mixed plaster; Small unidentified accessory, high order, mineral present. Also hornblende -- rare.

13M008 - Large porhcals quartz, subangular to subround. Some secondary calcite and some biological calcite. Finely divided hematite dispersed throughout but not much in blobs, some chert. Some unidentified accessory high order mineral present. No twinned feldspars.

14M038 - Medium subangular to subround quartz. Rare blobs of hematite, fairly porous, lots of biological calcite - whole organisms, some chert and unidentified high order accessory mineral. Also grog or possibly beach rock with hornblende, it doesn't have the finely divided hematite in it

19C1 - Medium grain subangular to subround quartz. Biological calcite present and also secondary calcite mixed with it. Chert present. Matrix dark with much finely divided hematite. Some unidentified high order accessory mineral.

07M006 B_1 - Small to medium subangular to subround quartz distantly spaced in matrix (quartz as prevalent as in previous sections). Matrix has both finely divided and dispersed hematite and large blobs. Secondary calcite but also biological calcite present. Matrix has fine cracks.

07M006 B_2 - Appears the same but biological calcite larger, and possibly hornblende, also hematite.

07M006 B_3 - Appears the same to 07M006B1 but with huge pieces of hematite.

07P015$_1$ - Medium to large quartz, subangular to subround with much biological cacite, fairly porous. No twinning feldspars.

07P015$_2$ - Appears similar, pieces of beach rock (small angular quartz cemented by secondary calcite, seems like a beach deposit) Rare, unidentified accessory mineral (high order birefringence)

07P037$_1$ - Small to medium mostly subangular quartz in a very dark (iron pigment) matrix. Possible pieces of chert -- fairly large. Plagioclase [redacted] (high cacite) feldspars rare but present. Unidentified high order accessory, small and rare -- possibly hornblende in addition to mica. Some large particals of hematite and some quartz grains show stress patterns. Biological cacite present but rare.

07P037$_2$ - Same as above but quartz more densely packed. Sodium calcium feldspars twinning on rare particals. Rare biological calcite, isolated large particals, not small and scattered. Probably presence of small detrital hornblende and mica. Small pieces of chert also! Evidence of blank spots in the matrix, (doesn't look like grog -- looks like poor mixture)

Guillou, R.B., & Glass, J.C., ...
the beachsands of Puerto Rico," USGS Bull. 1042-I.

Puerto Rico

geology - late Mesozoic + poss. early Tertiary range of granites, andesites, + diorites in island center running E-W flanked on N + S by Tertiary calcareous rocks, marine limestones. Overlain in low areas by Quaternary alluvia, beach sand, dune sand, & clay.

beaches - swamps in NE as well as beach rock outcrops (bedrock or consolidated recent sands).

NE beaches:

Cabezas de San Juan to Punta Uvero (15 mi)

rocky points separating low sand dunes in coves; mostly outcrops of consolidated sand beach rock on & offshore; swamps E of Rio Espiritu Santo (near Pt. Uvero). Calcareous sand predominates; non-calcareous mat'ls more common at estuary locations but not major component. Source of sediments: volcanic rocks of interior — generally andesitic tuffs, flows, intrusives, etc.

Punta Uvero to Punta Vacia Talega (5 mi)

consolidated + unconsol. sands; mostly fine grained quartz, some magnetite locally, few calcareous fgmts; source: volcanics of plutonic + intrusive interior fms.

Punta Vacia Talega to Punta Salinas (19 mi)

similar to above but with low dunes, sea cliffs, + swamps/lagoons; predom. calcareous sand w/abunt. nonmetal. minerals; common consolidated sand beach rock. Source as above.

Potential heavy mineral associates:

magnetite - usually small grains

✓ sphene - yellow to pale brown; rare but widely distr. + occurs in hornblendic sands of N shore. Usu. wedge-shaped 1-3 mm. across.

✓ zircon - clear, colorless, 1 mm. long. ||

✓ epidote ||

✓ garnet

olivine

hematite

spinel

✓ pyroxene (augite) 36-45°

✓ zoisite ||

? biotite ||

✓ diopside -37°-44°

✓ hornblende 12-30°

lamprobolite 0-12°

SAJU 2	Matrix	Quartz	Void	Hematite	Chert	Hornblende	Crystal Agg
percentage	.39	.35	.18	.01	.05	.01	.01

Note- Crystal Aggregate is high order with no extinction and very small crystals, probably calcareous and possibly artificial.
Minerals present 1% or less -- feldspars: single twinned sodium potassium (NaK), zoisite (epidote), and magnetite

Quartz grains average size	.2 to .4 mm across
feldspars	.1 to .2 mm
chert (similar to quartz)	.2 to .4 mm
voids - sometimes large	.5 to 2mm
hornblende	.1mm

SAJU 3	Matrix	Quartz	Void	Hematite	Chert	Crystal Agg	Fossil	Diop
percentage	.50	.27	.14	.02	.01	.04	.01	

Also present in 1% or less;- hornblende, epidote; large fragments of unpigmented calcarious material possibly beach rocks, small spherules quite common, less than .1 mm in general (hard to tell if they are in the plane of the section) possibly flyash or bubbles.

Quartz grains average size	.15 to .35 mm
fossils	.1 to .4mm
beachrock fragments	2 to 4mm
diopside	.1 to .2mm
hornblende	.1mm

SAJU 4 1	Matrix	Quartz	Void	Hematite	Chert	Crystal Agg.	Fossil
percentage	.27	.18	.43	.01	.01	.06	.04

Also present in 1% or less;- diopside, hornblende, zircon

quartz fragments average size	.3 to 2 mm
voids	.5 to 3mm
fossils	.5 to 1mm

SAJU 4 2	Matrix	Quartz	Void
percentage	same		

Also present in 1% or less,--
Similar to above, same grain sizes, many bubbles probably not flyash
Addition of fairly large pieces of magnetite. In both SAJU 4 calcarious material large and apparent.

SAJU S_1

	Matrix	Quartz	Void	Crystal Agg.	Magnetite
percentage	.57	.29	.09	.03	.02

Also present in less than 1% -- hematite, ~~a~~hornblende. Only plane polarized light can see ~~finely~~ large reddish areas, pigmented by finely divided hematite possibly brick dust.

Quartz grain sizes ~~average~~	.1 to .5 mm	
Voids	.2 to 1.5 mm	Under X-Nicols
Crystal Aggregates	up to 1mm	they are dark and lack l
Magnetite average	.2 mm	matrix.
Long Reddish Areas	4 to 6 mm - smaller ones also interspersed at ~~a~~ about .2mm	

SAJU S_2

Similar ~~b~~ to SAJU S_1 but cuts through are large area of reddish matrix under plane polarized lighted. Bubbles are also present. Particles of magnetite are also present as well as quartz. No particles of crystal aggregate are present. ~~No f~~.

SAJU S_3 Similar to SAJU S_1 with small reddish particles, probably brick dust. Epidote present, along with hornblende, ~~fossil~~, voids filled with calcareous material. Some of the large crystal aggregate appear to be dissolving from the inside. Magnetite also present.

07M006B$_1$

matrix	quartz	hematite	void	fossil
.58	.06	.27	.02	.07

present at less than 1% = magnetite, diopside (?)
section shows layering: smooth outer surface is thinly encrusted with secondary calcite, then next 4 mm. are composed of aggrega in a fine matrix with minute hematite giving pink color — below this at inner edge of section is a grayer matrix of dark particles .05–.1 mm. that are eroded + surrounded by acicular spherulites (colorless but length fast) – unknown mineral, possibly synthetic.

hematite sizes	~~.05 to .25 mm~~ .5 to 2.5 mm
fossils	~~.07 to .15 mm~~ .7 to 1.5 mm
qtz	~~.05 to .07 mm~~ .5 to .7 mm

07M006B$_2$ same as above; identical layering
also present below 1% hornblende, frag. beachrock (cemented calcareous w/incl. of qtz + fossils.

07M006B$_3$ as above, w/beachrock inclusions
very little of spherulitic layer (innermost) still sticks to the outer matrix.
in each 07M006B slide are low birefringent grains like qtz but with corrosion on margins penetrating into grain along 2 oblique directions — possibly sanidine feldspar (no twinning planes).

07P105$_1$

quartz	matrix	beachrock	fossil	void
.30	.52	.04	.09	.05

present at less than 1% — magnetite, epidote

qtz sizes	~~.05 - .08 mm~~	.5 - .8 mm
beachrock	~~.05 - 1.5 mm.~~	.5 - 1.5 mm
voids	~~.05 - 1 mm~~	.5 - 1 mm
fossils	~~.03 - 1.5 mm~~	.3 - 1.5 mm.

07P105$_2$ same as above.

07P037$_1$

quartz	matrix	void	hematite	beachrock	chert	augite	diopside	fossil	hornbl.	twinned feldspar
.27	.57	.06	.02	.02	.01	.01	.01	.01	.01	.01

heavy minerals more frequent - less fossil content; possibly not beach derived aggregate or mixed

quartz sizes	.2 - .7 mm.
hematite	.1 - 1 mm.
fossil	.3 - 1 mm.
beachrock	.3 - .7 mm.
feldspar	like qtz
chert	.2 - 1.2 mm.

07P037$_2$ same as above; but aggregate more concentrated, less matrix + more qtz. (closer to 40/40 %)

01M007

matrix	qtz	void	fossil	chert
.56	.19	.16	.08	.01

also present < 1% - hematite, hornblende, diopside?

qtz sizes	.15 - .7 mm.
fossil	.2 - 2.5 mm.
voids	.2 - 1.3 mm.

many voids are nearly circular — gas bubbles?

10m1047 matrix quartz beachrock void hematite fossil hornblende epidote
.46 .26 .21 .03 .01 .01 .01 .01
also present < 1% — magnetite
beachrock fgmts most prominent
qtz sizes .2 - 1 mm.
beachrock .5 - 1.5 mm.
fossil .3 - .7 mm.
voids .2 - .5 mm.
hornblende .1 - .6 mm.
layering of plaster(?) on one side — plaster has more biological calcite (poss. up to 20%) with beachrock + qtz. — definite boundary with mineral + texture difference. Size of aggreg. in plaster also smaller.

13m008 matrix qtz fossil void hematite beachrock sec. calcite
.57 .34 .13 .08 .01 .06 .01
other mineral < 1% - zircon (?), hornblende, magnetite, chert
qtz sizes .3 - 1 mm.
fossils .5 - 1.2 mm
beachrock .5 - 2.5 mm.

14m038 qtz. matrix void hematite fossil beachrock
.27 .45 .12 .01 .07 .08
also present < 1% — hornblende, magnetite, augite(?) or diopside, chert
smaller fossils, more beachrock than above
qtz sizes .3 - 1.5 mm.
fossils .2 - 1.7 mm.
hornblende up. to .3 mm.
beachrock up to 3 mm.

19C1 matrix qtz void hematite fossil beachrock chert
.41 .26 .13 .01 .04 .11 .03
also present < 1% zircon?, magnetite, diopside/augite?
qtz sizes

APPENDIX D.

Petrographic Analysis of Selected Masonry Samples from El Morro and El Cañuelo

Gregory J. Cavallo
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Corona, N.Y. 11368

Ms. Judy Jacob

November 2, 1989

Dear Ms. Jacob,

This study was undertaken to gain a better understanding of the constituents of mortars in the Castillo del Morro in San Juan, Puerto Rico. Thin sections of mortar, stucco and hormigon were examined petrographically in order to determine a source for the aggregate (locally acquired, or imported), the mineralogical composition of the aggregate and whether the hormigon could be considered hydraulic. In addition to the laboratory study , the geologic literature was reviewed for any studies describing the rocks and minerals from the San Juan area.

It was necessary to identify the mineralogical composition of the local rocks and alluvium for use as a basis for understanding the aggregate of the mortars . A search of the geologic literature identified three studies on the geology of Puerto Rico: Guillou and Glass (1957), Kaye (1959), Gelabert (1964). Gelabert (1964) describes the geology near the el Morro as consisting of cemented dune sand, beach sands and beach rock. The cemented dune sand is described as consisting of "well rounded grains of calcite, quartz volcanic rocks and shell gragments {sic}." Beach sands are of unconsolidated "well rounded, coarse to medium grained sands composed predominantly of quartz, calcite, magnetite and volcanic rock fragments". Gelabert further speculates that the beach sands have an igneous source at the interior of the island and were transported to the coast by rivers and distributed by littoral currents. Beach rock occurs in the intertidal zone and is "composed mainly of quartz, and calcite grains cemented by calcium carbonate or iron oxide."

Guillou and Glass (1957) went a step further. They made a reconnaissance study of the beaches in Puerto Rico to identify economic heavy minerals and try to locate their sources. The major mineralogical components of the "Black sands, 'which are the heavy darkly colored minerals of alluvium and marine deposits'," in order of decreasing percentage are magnetite, chromite, epidote, garnet, hematite, ilmenite, limonite, olivine, pyroxene, sphene (titanite), spinel and zircon. They sampled sands from two locations near el Morro: # 3C and # 4A, see Table 1. # 3C sands are composed primarily of a magnetic component, which

is assumed to be mostly magnetite, 71%. The remaining nonmagnetic heavy sands are composed of diopside> epidote>> chlorite> hornblende> limonite = actinolite. # 4A sands are approximately 50% magnetite, with the nonmagnetitic fraction augite>> epidote> minor garnet, minor sphene. In addition to the reviews of the geologic literature, the sand sample you brought back from Puerto Rico taken approximately 1 Km from el Morro was described using a binocular scope without the aid of a thin section. These analyses represent the closest sampling locations to el Morro found in the literature and physically obtained for this study.

Thin Section Descriptions

M066 Mostly quartz, subangular to surrounded occasional euhedral grains found. Some quartz grains show strain and others are polycrystalline. Minor amount of fossils and fossil fragments, these appear to be mostly shell fragments. Trace amounts of euhedral magnetite. Trace amounts of what appears to be an epidote, a pyroxene and a plagioclase feldspar. The matrix is composed of a mixture of microcrystalline to cryptocrystalline carbonate and a cryptocrystalline iron oxide, probably hematite. Some of the matrix is recrystallized.

Quartz 60-70%	.2mm to .75mm in diameter
Fossil fragments <5%	variable
Magnetite <1%	
Feldspar <1%	
Epidote <1%	
Matrix 25-30%	<<.01mm

M004 Mostly quartz, subangular to subrounded. Minor amounts of fossils and fossil fragments, usually shell material. Minor amounts of iron oxide with included quartz. Trace amounts of hematite grains and magnetite. Some fossil and fossil fragments show signs of recrystallized calcite. The matrix is composed of cryptocrystalline iron oxide, probably hematite.

Quartz 25-40%	.1mm-.3mm
Fossil fragments 1-5%	
Magnetite <1%	
Hematite <1%	
Matrix 50-60%	<.01mm

M143A This thin section can be divided into two distinct areas based on color; there is a reddish area consisting of quartz. Which is subangular and showing some sign of strain while others are polycrystalline with minor amounts of opaques, probably hematite and magnetite. The matrix is a cryptocrystalline iron oxide, (hematite?). The lighter colored areas consist of quartz, subangular to subrounded, and minor amounts of fossil fragments some of which appear to be recrystallized. Trace amounts of magnetite and possibly hematite. The matrix is cryptocrystalline

carbonate. Vugs seen in thin section appear to due to plucking of fossils and fossil fragments during thin section preparation.

Reddish Area	Lighter Area
Quartz 15-20% .1mm to .3mm	Quartz 10-15% .1mm to .5mm
Feldspar (plag) <1%	F. Fragments 10-20% variable
Hornblende <1%	in size from .1mm to 1.0mm
Matrix 75-85% <.01mm	Matrix 60-70% <.01mm

M143B Quartz, sub angular to subrounded and variable in size. Some show signs of strain, others are polycrystalline. Trace amounts of volcanic glass with gas inclusions? Trace amounts of lighter colored hematite with quartz inclusions, lithic fragments? Trace plagioclase feldspar, blebs of more opaque hematite than matrix. Trace amounts of magnetite and trace pore space. The matrix is composed of cryptocrystalline hematite.

Quartz 20%	variable .1mm to 1.0mm mostly <.5mm
Opaque Hematite <5%	.2mm-.3mm
Plagioclase feld. <1%	
Vugs <1%	
Matrix 75-80%	<.01mm

M133 Mostly quartz, subrounded, euhedral? occasionally polycrystalline. Fossils and fossil fragments,(ostracod shells?), some showing signs of recrystallization. Minor amounts of opaques, magnetite, occasionally containing isotropic component which appears to be volcanic glass. Trace amounts of diopside, epidote and hematite. Matrix is cryptocrystalline carbonate with trace amounts of glass particles. The matrix is composed of cryptocrystalline carbonate with components of volcanic glass.

Quartz 30-40%	.3 to .75mm
Fossils 10-15%	.45 to 1.2mm
Magnetite <5%	.1mm to .3mm
Hematite <1%	<.05mm variable
Diopside <1%	.1mm to .3mm
Epidote <1%	.1mm to .3mm
Matrix 40 to 50%	<.01mm

M002 Mostly quartz, subangular to subrounded, sometimes polycrystalline. Minor amounts of fossil material, some showing signs of recrystallization. Minor amounts of magnetite, occurring as discreet grains and included in the matrix as very small grains. Trace amounts of plagioclase feldspar with alteration along twin planes, also trace amounts of untwinned feldspar, probably a K or Na feldspar. One large vuggy inclusion of carbonate 5-7mm in diameter with included quartz crystals. Trace amounts of diopside grains and hematite grains.
The matrix is a curious mixture of microcrystalline to cryptocrystalline hematite and carbonate with a variety of accessory minerals including, magnetite, hematite and trace glass? Does not appear to be homogeneous, There are areas

that are mostly carbonate with very little hematite; the reverse is also true.

Quartz	40-50%	.2 to .5mm
Fossil Material	<5%	.5 up to 1.0 variable
Magnetite	<5%	.2mm
K-Na feldspar	<1%	
Plagioclase feld.	<1%	
Hematite	<1%	
Matrix	30-40%	<.01mm

M001 Mostly quartz, subangular to subrounded. Fossil material some showing signs of recrystallized rims. Minor to trace amounts of plagioclase feldspars with alteration along twin planes. Trace hornblende, K-Na feldspar, one grain has a perthitic texture IE cross hatched consisting of albite and microcline, a further indication of volcanic origin. Trace magnetite found as discreet grains <.2m and in the matrix as microcrystalline grains The matrix consists of cryptocrystalline iron oxide, hematite and carbonate. The relationship of the hematite and the carbonate is similar to that found in sample M002.

Quartz	60-70%	.3mm
Fossil Material	5-10%	.5mm
Plagioclase	<5%	.2mm to .3mm
Hornblende	<1%	.2mm to .3mm
K-Na feldspar	<1%	.2 mm to .3mm
Magnetite	<1%	.2mm, <.05mm
Matrix	20-30%	<.01mm

M006 Mostly quartz, subangular. Fossil material. Minor amounts of K-Na feldspar with a trace amount of plagioclase feldspar showing signs of alteration. Minor amounts of magnetite and blebs of hematite. A large discreet area of lightly colored material occupies approximately 10% of the entire thin section. It consists of fossil material with minor amount of quartz, hematite and magnetite in a matrix of carbonate. The matrix is a mixture of carbonate sometimes interspersed with hematite, magnetite and a very fine unidentified cryptocrystalline mineral.

Quartz	40%	.2mm to .4mm
Fossil Material	10-15%	.15mm to .6mm
K-Na feldspar	<5%	.2mm to .4mm
Magnetite	<5%	.2mm, <.05mm
Plagioclase	<1%	
Hematite	<1%	
Matrix	20-25%	<.01mm

M126 Quartz, subrounded occasionally polycrystalline. Fossil fragments consisting of shell fragments and what appear to be ostrocod debris some of which appear to be recrystallized. Large red lithic fragments, up to 1.5mm in diameter composed of euhedral untwinned feldspar, K-Na feldspar, blebs of hematite, hornblende, polycrystalline quartz, all the mineral are heavily stained with an iron

oxide. Minor amounts of magnetite. Trace plagioclase feldspar and very fine grained glassy material included in the quartz and feldspar. The matrix is composed of carbonate material with trace amounts of hornblende fragments.

Quartz	10%	.3mm
Fossil F.	10-20%	.2mm up to 1.0mm
Lithic F.	10-20%	up to 1.5mm
Magnetite	<5%	Variable
Plagioclase	Tr.	
Matrix	40-50%	<.01mm

M137 Quartz subangular to subrounded, some quartz grains showing signs of strain and occasional grain shows inclusions of magnetite. Fossil material mostly shell fragments with some showing signs of recrystallization, usually around the edges of fragments. Trace pleochroic amphibole. Trace amounts of anhedral magnetite. A small high relief mineral? The matrix is composed of a cryptocrystalline groundmass of carbonate.

Quartz	50%	.2mm to .5mm
Fossil F.	20-30%	variable .3mm to >1.0mm
Amphibole	<1%	variable .1mm to .3mm
Magnetite	<1%	variable
Matrix	25-30%	<.01

M135 There are two major components in this sample, red clasts and the minerals they include and everything else. The large red clasts are variable in size and range up to 3mm, consisting of euhedral quartz 10%, with some grains showing signs of strain, other are polycrystalline, trace amounts of plagioclase feldspar, amphibole and magnetite, with cryptocrystalline hematite as the matrix. These clasts appear to be deliberately broken up pieces that have been added to the host material. The composition of the nonclast component is quartz, subangular to subrounded. Fossil material. Trace epidote and magnetite. The matrix is composed of a muddy cryptocrystalline carbonate, organic material?

Red clasts	30%	variable up to 3mm
Quartz	10-15%	variable .2 to .3mm
Fossil F.	10-15%	variable up to .5mm
Vugs	<2%	
Magnetite	<3%	variable
Amphibole	Tr.	
Epidote	Tr	
Matrix	30-40%	<.01mm

M136 Quartz, subangular to subrounded. Fossil fragments, which appear similar to the fossils and fossil fragments seen in other thin section. Minor amounts of plagioclase feldspar, albite twinning evident, more plagioclase than seen in other thin sections. This may be indicative of a source closer to the original igneous rock. Trace amounts

of opaques including hematite, magnetite, and rounded diopside. The matrix is a cryptocrystalline carbonate.

Quartz	35%	.1 to .3mm
Fossil frag.	25-30%	.1 to.5mm variable
Plagioclase	<1%	.1mm to.3mm variable
Magnetite	tr	
Diopside	tr	
Hematite	tr	
Matrix	30-40%	<< .01mm

M116 Fossil fragments. Quartz, subrounded with inclusions of magnetite,(zircon?) and occasional inclusions of epidote. Trace amounts of magnetite, euhedral and trace amounts of amphibole, good cleavage noted. Matrix is a cryptocrystalline carbonate.

Fossil fragments	40-50%	.2 to.6mm
Quartz	30%	.2 to.5mm
Magnetite	tr	
Zircon	tr	
Epidote	tr	
Amphibole	tr	
Matrix	20-30%	<<.01mm

Beach Sand Quartz, subangular to subrounded, occasionally included with magnetite or coated with magnetite. Fossil material, subrounded to rounded, variable in color and size. Some are distinctive fossil fragments possibly of foramnifora? shell fragments? coral? Trace amounts of magnetite (not associated with quartz). Trace amounts of amphibole and pyroxene. Some of the quartz and fossil fragment grains appear to be coated with an Fe-oxide which makes them susceptible to a hand magnet.

Quartz	50-60%	.4mm to .75mm
Fossil Fragments	40-50%	.3mm to 1.00mm
Amphibole	tr	
Pyroxene	tr	
Magnetite	tr	

Void percentages are usually not reported because they may have been induced by sample preparation, for example plucking of grains, friable sample and a variety of other mechanical means. Only void spaces that have been determined to have been naturally occurring as evidenced by crystal growing into a pore space are reported.

Conclusion

Most of the thin sections studied contain varying amounts of quartz and fossil material. Quartz and the accessory minerals indicate an igneous source. The strained texture of some quartz grains, the fluid inclusions, the

occasional glass and magnetite inclusions and the polycrystalline nature of some quartz grains indicates a volcanic source. A likely source for this material is from the interior of the island which has abundant outcroppings of Cretaceous and Tertiary volcanics. Gelabert (1964) speculates that the beach sands of Puerto Rico are derived from these sources and have been transported by rivers and distributed by littoral currents. Guillou and Glass (1957) found similar mineral assemblages including magnetite, amphibole, pyroxene and Fe-oxide when trying to identify economic mineral deposits through a reconnaissance study of beach sands of Puerto Rico. The fossil materials are, in general of unknown species to me, some I suspect to be foramnifora and possible bryozoan debris. A paleontologist may be able to identify them more precisely. This information would assist in narrowing the possible locations for the aggregate.

Although the minerals described in the thin sections above are found in a variety of geologic settings and are not unique to any one location, the strong correlation between the mineralogy of the beach sand of Puerto Rico cited in the literature and the mineralogical composition of the beach sand taken near el Morro and those identified in the mortar strongly indicate a local source for the aggregate.

Sincerely,

Gregory J. Cavallo

Mortar Numbers and Location

SAJU	200	M066	Mortar from low counterscarp north of Ochoa Bastion, south end.
SAJU	200	M004	Stucco from northeast scarp of Ochoa Bastion.
SAJU	200	M143a	HORMIGON from el Morro, third casemate from south of the northwest side of the Plaza.
SAJU	200	M143b	Brick from the HORMIGON from el Morro, third casemate from the south on the northwest side of the Plaza.
SAJU	200	M133	Stucco from the center 1897 structure on top of el Morro.
SAJU	200	M002	Mortar from the retaining wall by the water, north of Ochoa Bastion.
SAJU	200	M001	Mortar behind stone from the retaining wall by water, north of Ochoa Bastion.
SAJU	200	M006	Mortar from the northeast scarp of Ochoa Bastion.
SAJU	200	M126	HORMIGON from el Canuelo, east corner.
SAJU	200	M137	Mortar from 1908 portion of lighthouse.
SAJU	200	M135	HORMIGON lining gutter on ramp to Austria Bastion.
SAJU	200	M136	Stucco from southwest scarp of Austria Bastion.
SAJU	200	M116	Stucco from Mercado Bastion interior, west wall, south of embrasure.

Beach sand

Table #1
From Guillou and Glass (1957)

APPENDIX E.

Problems of Biological Growth on Stone Materials with Special Reference to the Fortifications of San Juan NHS, Old San Juan, Puerto Rico

Problems of Biological Growth on Stone Materials with Special Reference to the Fortifications of San Juan NHS, Old San Juan, Puerto Rico

Prepared for

The National Park Service

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March 5, 1991

Problems of Biological Growth on Stone Materials with Special Reference to
Old San Juan, Puerto Rico

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Introduction

The fortifications of San Juan NHS are a formidable structure located near the Old City of San Juan, Puerto Rico. The Old City was established in or about 1521 on an elongated island along the north side of San Juan Bay. The ocean side of the island has steep hillside ranging from about 30 to 100 feet in elevation. El Morro is located along the western edge with the old fortress of San Cristobal and its outworks to the east. The top elevation of the outer perimeter fortress is approximately 73 feet above mean sea level while the inner fortress is approximately 120 feet above sea level. As an imposing and historic structure, El Morro and San Cristobal battlements have few equals in the New World.

The fortifications have, naturally, been subjected to erosion resulting from the physical actions of wind, rain, and the ocean. Aside from the physically destructive processes of wind and water abrasion, biological growths of autotrophic and heterotrophic flora have been noted on the stonework. The purpose of this report is to assess this microbiological component and its potential effect on the stone.

Climatological Factors

The northeast trade winds dominate the macro-scale weather patterns. The fortifications are situated on the north, or windward coast of the island, which is exposed to more wave action than are the other coasts. The extent of damage to the fortifications that can be attributed to this physical process is unknown at present but is presumably confined to the exposed seaward slopes. Tidal exclusion in the San Juan area is negligible at a 1.1-foot mean-tidal range. Of the four coasts of Puerto Rico, the north coast environment is unique in that it deepens rapidly with little shoaling and is exposed to heavy swells that originate with North Atlantic storms. These factors combine to allow for the development of large waves due to an uninterrupted length of wave fetch across the Atlantic Ocean for northeast to northwest winds. As reported in Kaye (1959), "it is not unusual, given shoreline features to see spray shoot more then 100 feet in the air."

Construction Materials Utilized in Fortification Construction

According to Gelabert (1964), when the Spaniards constructed él Morro and San Cristobal they utilized cut stone, which is cemented dune sand. Typically, this stone was cut

into blocks to form walls. However, in some structures rock outcrops were sculpted to form walls. Once cut and prepared, these stones tended to harden, which increased their durability.

Given the above it is not surprising that additional analysis of selected portions of San Cristobal (A.Gilbert, Fordham University) noted the presence of quartz with a tendency towards grain rounding with much variability. Gilbert also reported the presence of significant amounts of biological calcite with pieces of the larger Mollusca, which he suspected came from beach deposits of recent date.

In some portions of el Morro, types of stucco materials appear to have been placed over the cut stone blocks. Selected crusts of these stucco materials were analyzed by the Calspan Corporation by an X-ray spectrographic technique (letter communication, L. Leonard to Walter Sedovic). The analysis was from the interior of a fractured sample and showed the presence of silicon and calcium. Comparison of interior and exterior samples showed the presence of high concentrations of sulfur on the outside crusts in addition to chlorine and iron. It is unclear whether these samples were taken from a coastal area exposed to wind or salt spray. If they were, this could explain the presence of

chlorine and to a lesser extent sulfur and iron, which can be residues left on the exposed surface from salt spray.

Materials and Methods

Samples of stone from el Abanico (the north wall of the counterscarp) were collected by the National Park Service during July 1989. The samples were subjected to analysis by our project team via scanning electron microscopy, energy dispersive X-ray spectrometric analysis, and cultural isolation techniques.

Scanning electron microscopy-energy dispersive X-ray spectroscopy

Samples of the stone were mounted on either aluminum pin-type mounts or spectroscopically pure carbon pin-type mounts, coated with approximately 10 nm of gold-palladium or 10 nm of spectroscopically pure carbon, and examined in a scanning electron microscope with attached energy dispersive X-ray spectrometer.

Culturing studies

Samples of the stone were inoculated onto a variety of culture media for fungi and bacteria. These media included nutrient agar, Sabaroud's agar, and potato dextrose agar.

Results

Scanning electron micrographs taken from samples of el Abanico are presented in figures 1 through 7. The surface of the stone was extensively covered with microbiological growths. Figures 1-3 show the extensive network of fungal hyphae that covers large parts of the samples. Even in apparently microbiologically-clear areas, at higher magnifications fungal hyphae and other microorganisms can be found, figs. 4 and 5. In other samples, the microorganisms had completely covered the surface of the stone with a biological "mat," figs. 6 and 7. Figure 6 shows an apparent layer of microbial exudate covering the upper half of the image. One long fungal hypha is visible in the center bottom, coming out of the layer. Figure 7 shows what look like rod-shaped bacteria in a layer of microbial exudate.

The major biological constituents found were the following:

Fungi:

All isolated from sample 1, el Abanico Counterscarp, N. Wall

Fusarium oxysporium

Mycelia steritia (Hyahine)

Mycelia steritia (Dane)

Cladosporium cladosporioides

Both heterotrophic and autotrophic organisms were noted.
Also noted were bryophytes, algae, and bacteria. It was not possible to determine genera and/or species for these groups due to budgetary constraints.

Energy dispersive X-ray spectroscopy revealed high levels of calcium, probably in the form of calcite or aragonite; minerals containing magnesium, aluminum, silicon (probably magnesium-aluminum-silicates); silicon-rich crystals, probably quartz (sand); and small amounts of iron, sulfur, potassium, vanadium (often found near oil refineries), and zinc.

Discussion

Physical breakdown of materials is a subject that has long been studied, with the aim of providing more durable materials. Deterioration of stone, whether in a man-made monument or in its natural form, is a constant and natural phenomenon, and can occur through many causes (Clifton, 1980; Plenderlieth, 1956; Winkler, 1982; Amoroso and Fassina, 1983; Koestler et al., 1985). Recently researchers

have begun to investigate how biological phenomena--at times in synergy with physical effects--can exacerbate deterioration of stone materials. Studies by Koestler et al. (1985; 1987a,b) have begun to bring out the importance of microbes in the breakdown and recrystallization of stone materials. Heretofore, microbes were considered to play a minor role, if any, in stone deterioration. In our view, though, microbiological attack can actively promote material decay and may act in synergy with physical means of deterioration. Studies by Webly (1963), Henderson and Duff (1963), and Hueck van der Plas (1968), among others, have shown fungi to be the more deleterious microorganisms. This is indeed clearly the case in tropical climates, where high relative humidity and temperatures, among other factors, exacerbate material decay.

The microorganisms found colonizing the surfaces and interiors of stone are essentially the same as normal soil microflora (Webley et al., 1963). They constitute a complex ecological community capable of carrying on the normal processes of stone weathering and soil formation. They include heterotrophs (e.g., fungi and some bacteria) and autotrophs (e.g., algae, called photoautotrophs; and some genera of bacteria, called chemoautotrophs).

Heterotrophic organisms are those that require organic nutrients (Stanier et al., 1976). Stone in the open air is likely to be covered and infiltrated with dirt and organic matter from rain, groundwater, airborne sources, and animal sources such as pigeon excrement, which has been seen to be a rich source of nutrients and encourages deterioration of marble statues (Bassi and Chiatante, 1976). Many bacterial heterotrophic species have been isolated from stone. These have been seen to contribute to the dissolution of siliceous and calcareous stones by the production of various organic acids, mainly 2-ketogluconic acid (Henderson and Duff, 1963). Bacteria isolated from sandstone monuments have been shown to have the ability to cause severe, rapid weight loss in sandstone by attack of the calcium matrix of the stone with organic acids (Lewis et al., 1987). Various fungi have also been isolated from and associated with decaying stone (Bassi and Chiatante, 1975; Koestler et al., 1985). These also attack stone by the production of various organic acids, such as oxalic, citric and fumaric acids.

Autotrophic organisms require inorganic nutrients, and prime among them are the algae, a source of stone deterioration, especially in warmer, tropical climates. Algae, like higher plants, perform oxygen evolving photosynthesis, and because they use light as their energy source they are referred to as photoautotrophs. Algae may form obscuring

and staining coats of growth over many surfaces. They also produce and secrete a variety of organic acids which can dissolve stone components, in addition to secreting proteins and sugars, which facilitate the growth of various heterotrophs. Algal growth depends on the presence of calcium and magnesium, which explains why algae are often seen on limestones, frescoes and other calcareous substances.

Other autotrophs are chemoautotrophs--organisms that can use inorganic compounds as substrates for energy sources and respiratory metabolism (Stanier et al., 1976). Chemoautotrophs such as sulfur oxidizing and nitrifying bacteria undoubtedly play a large part in the deterioration of stone monuments, but this is often downplayed, ignored, or even denied by many concerned with the problems of stone preservation. Studies done since the 1950's have demonstrated the importance of these types of bacteria in stone deterioration, and the stimulation of their activity by some heterotrophic organisms, which may help supply some nutrients (Sand and Bock, 1988; Lewis et al., 1988; Krumbein, 1972; Pochon et al., 1951; Krumbein, 1968; Pochon and Jaton, 1968).

Sulfur oxidizing bacteria obtain energy by the oxidation of reduced sulfur compounds--such as sulfur, sulfides and thiosulfates--to sulfites. Sulfites are readily con-

verted to sulfuric acid, which can react with calcium carbonate in limestone, marble and calcareous sandstones, and form calcium sulfate (gypsum salt). The calcium sulfate may either precipitate within the stone, causing spalling of stone, or may migrate in solution to the surface of the stone where it can form a crust of gypsum that eventually traps dirt and blackens the stone surface. Sulfur oxidizing bacteria such as Thiobacillus thiooxydans have been found in high numbers in many deteriorated stone monuments in urban and other environments (Barcellona-Vero and Monte Sila, 1976).

Nitrifying bacteria form nitric or nitrous acids, which can react with calcareous stones to form readily soluble calcium nitrate. This is either washed away or may form characteristic white crystalline deposits on stone or frescoes. The separation of bacteria into sulfur oxidizing bacteria and nitrifying bacteria is somewhat misleading since bacteria, like other microbes, can alter their metabolic pathways depending upon the availability of substrates (Dr. Eric May, Portsmouth Polytechnic, England, personal communication).

From the perspective of stone composition at el Abanico, the nonhomogeneous nature of stone would provide ample areas or nooks for microorganisms to attain a

foothold. The presence of calcium carbonate exposed to spray would tend to disassociate these materials and create voids in the stone surface. The presence of seawater spray would provide, in addition to water necessary for organism growth, selected trace constituents necessary for microbe growth and propagation. In such an environment, both autotrophs and heterotrophs could thrive. This is clearly evident in the SEM micrographs of the stone samples analyzed (figs. 1-7), which show the extensive network of microbial growth and microbial secretion products in many regions of the stone examined.

Stone composition of el Abanico characterizes the material as sedimentary in nature--being composed of a variety of materials, such as calcite and silica. This mixture of materials supports a diverse microbiological community, as was clearly seen in the samples examined for this report. Some of these microbes may dissolve the calcium carbonate binding media of the stone, by secretion of organic acids; others may attack the silica grains directly or indirectly by creation of a microbial "mat" that will retain moisture against the sand grains. Moisture held against sand grains will eventually increase in pH and result in dissolution of silica just from the pH increase. The extent of microbiological attack to the structure, separate from physicochemical deterioration, is difficult to assess, but the

presence of extensive growth does lead to the presumption that the biological problem is significant. The damage that communities of microbes can cause to stone has been discussed in a number of scientific studies (e.g., Koestler and Santoro 1988, 1989; Koestler et al., 1985).

It should be pointed out that a complicating factor when dealing with the effects of microorganism concentrations on stone surfaces is the possibility of a reduction in physical deterioration processes, such as those caused by wind abrasion, due to coverage of portions of the stone by a protective microbial "mat." Which effect predominates--protection or deterioration--as well as how much it will vary from place to place on a stone surface, and the determination of the relative importance of these effects on any particular surface would of course require extensive investigation.

It should also be noted here that microbial attack is not confined to the surface of the stone. Many studies have shown that microorganisms may penetrate from a depth of a few centimeters to almost a meter inside a stone, especially in the cases of porous limestones or sandstones (Krumbein, 1972; Myers and McCready, 1966). Therefore, weakening of the matrix of the stone may be occurring even if no apparent growth is visible on the exterior surfaces.

Follow-up Activities

In view of the optimal conditions for microorganism growth in the San Juan fortifications, at least on exposed surfaces, further studies are recommended as follows:

- Development and implementation of a field evaluation strategy to determine the extent of coverage of organisms on the stone surface and to assess the implication for stone loss due to microorganisms;

- Development and evaluation of control techniques for stone conservation based upon results of the field evaluation step.

Both steps may require extensive laboratory work, in addition to field studies to assess the applicability and longevity of any treatment.

We would be pleased to discuss the findings of this report, and to develop the above concepts into projects for the NPS.

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LIST OF FIGURES

Figure 1. Scanning electron micrograph taken at 500x. el Abanico stone surface. Note the extensive fungal network on the stone.

Figure 2. Scanning electron micrograph taken at 500x. Another sample of el Abanico stone showing extensive fungal-hyphal network.

Figure 3. Scanning electron micrograph taken at 2000x. Higher magnification view of fungal colony.

Figure 4. Scanning electron micrograph taken at 5000x. Relatively poorly colonized area of el Abanico stone. Note the presence though of some fungal growth tips.

Figure 5. Scanning electron micrograph taken at 4000x. Relatively poorly colonized area of el Abanico stone. The white mass in the lower half of the micrograph is associated with the fungal hyphae. Upper right shows a coccolith shell.

Figure 6. Scanning electron micrograph taken at 2000x. Biological secretions or "mat" in upper half of the figure. Exudate probably from a mixture of algae, bacteria and fungal.

Figure 7. Scanning electron micrograph taken at 2500x. Biological "mat" on surface of stone. Rod-like bacteria are apparent as are fungal growth tips.

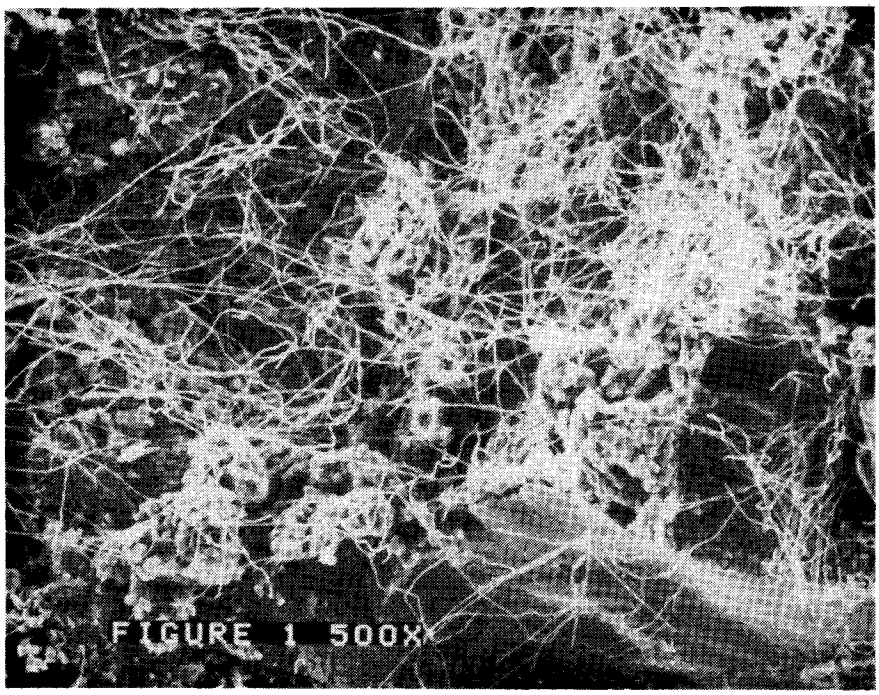
FIGURE 1 500X

FIGURE 2 500X

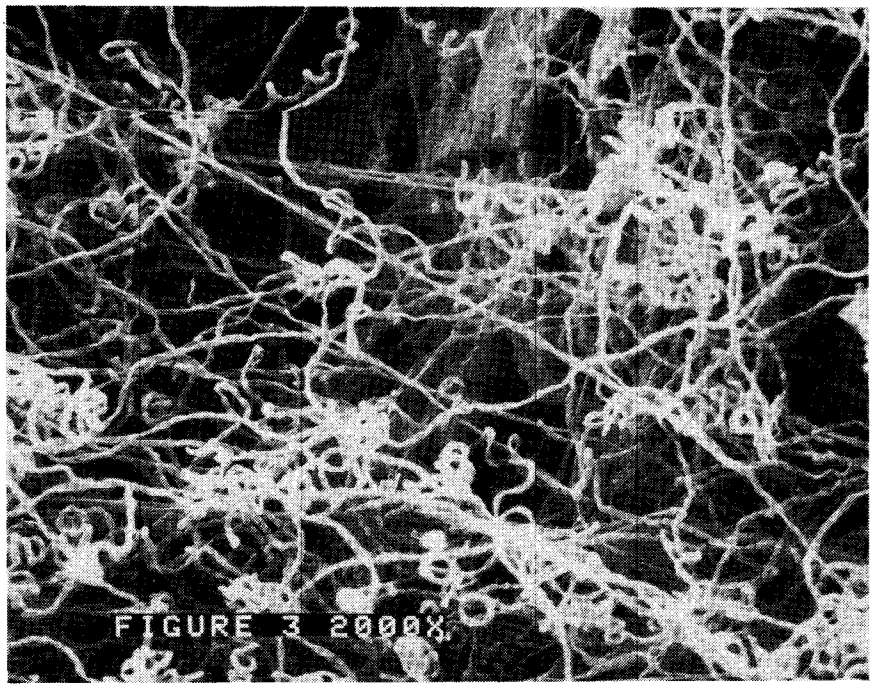

FIGURE 3 2000X

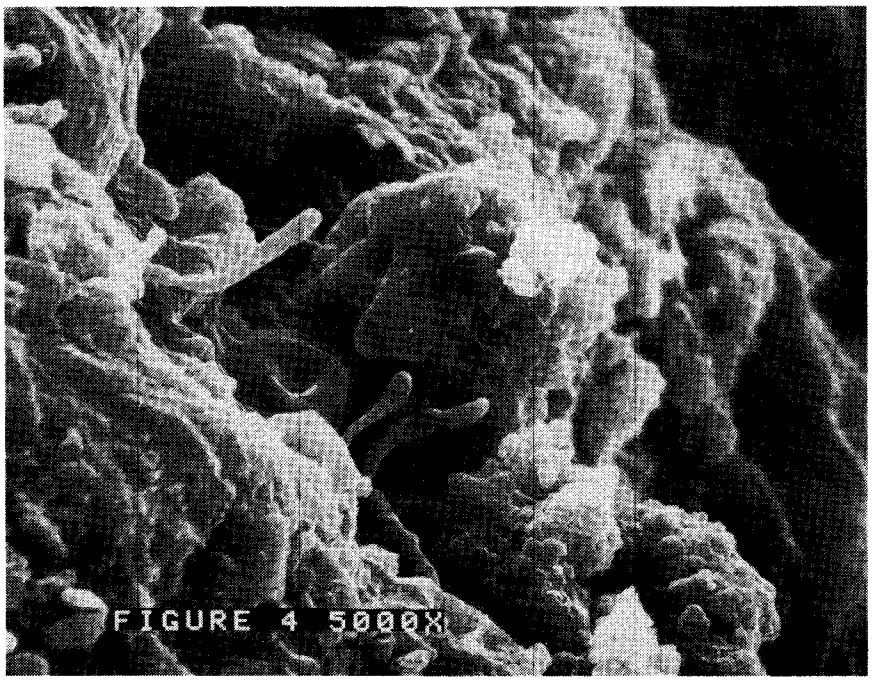

FIGURE 4 5000X

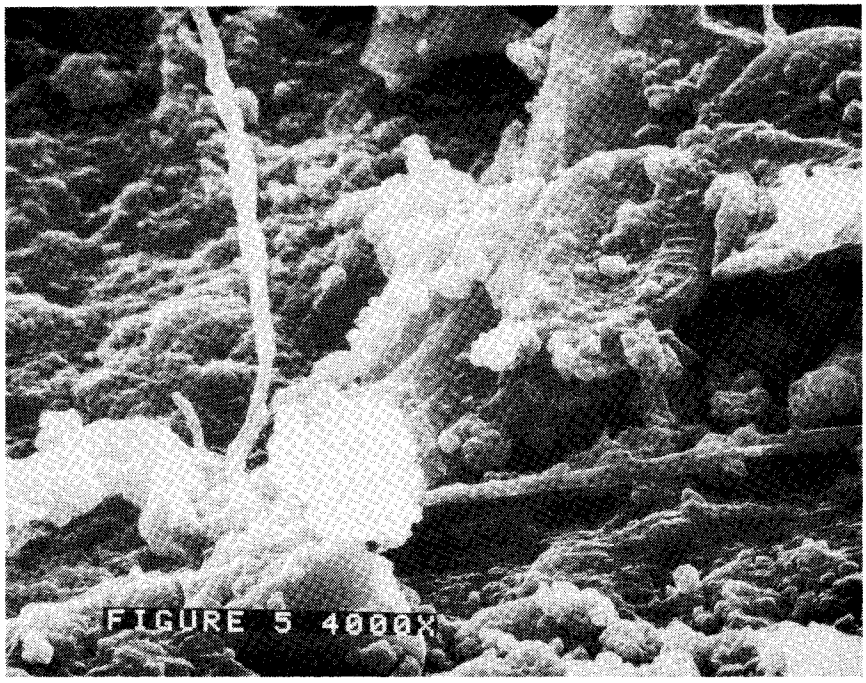
FIGURE 5 4000X

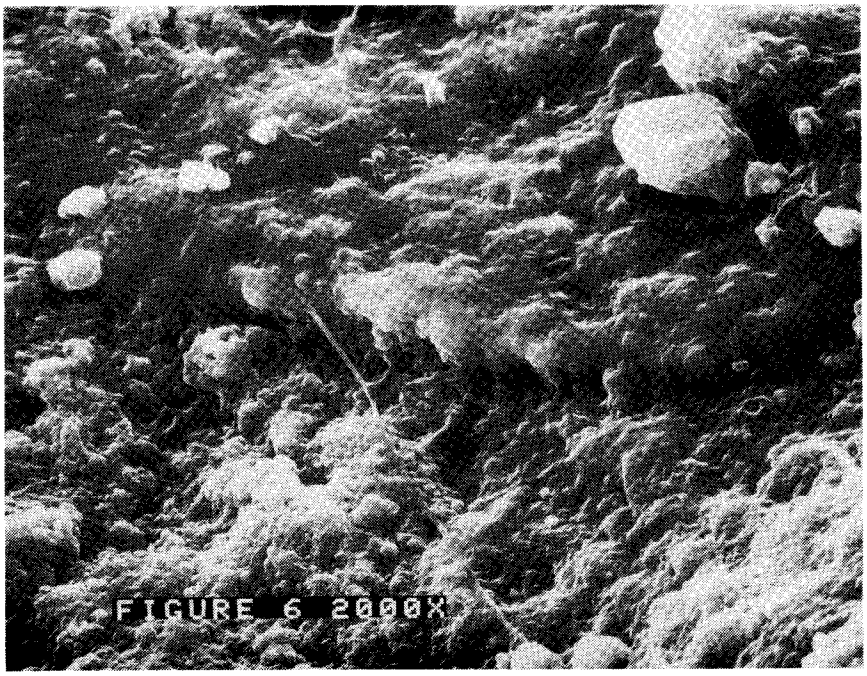
FIGURE 6 2000X

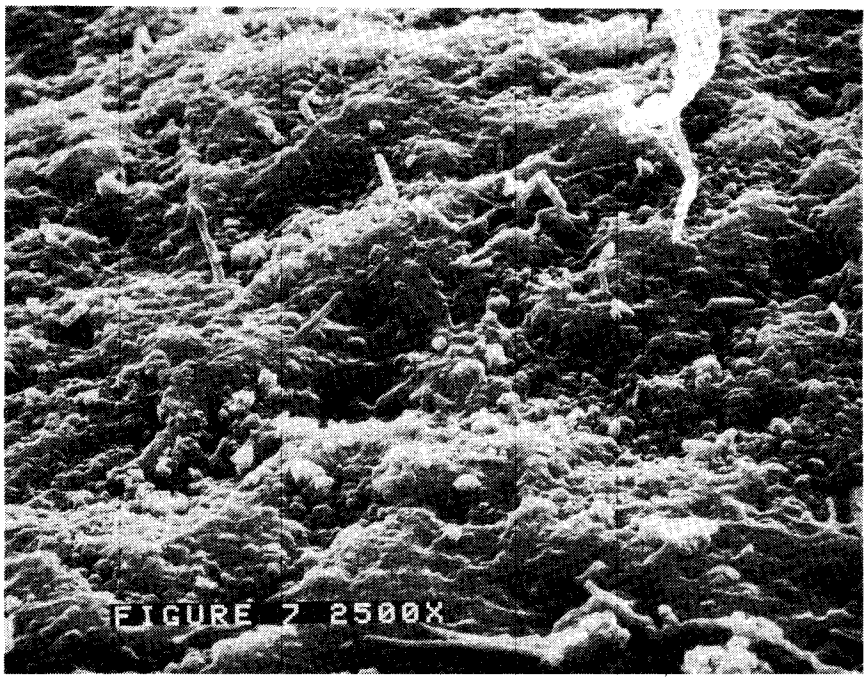
FIGURE 2 2500X

APPENDIX F.

Trip Report with Site Conditions

and

Analysis of Historic Stucco

United States Department of the Interior
NORTH ATLANTIC HISTORIC PRESERVATION CENTER
New York Office
26 Wall Street
New York, N.Y. 10005

IN REPLY REFER TO

July 19, 1988

Memorandum

To: Chief, Historic Preservation

From: Historical Architect, NAHPC

Subject: Trip Report for July 11-17, 1988
Preservation of Masonry
El Morro and the City Walls, SAJU

During the week of July 11 through 17, 1988, this office visited El Morro for the purpose of gathering data related to its masonry construction, in order to develop a better understanding of its condition and nature and, in turn, help to define appropriate strategies for its preservation. In attendance were Richard Crisson, Judy Jacob, you and I. Information resulting from this trip is to be included in the Historic Structure Report for the San Juan fortifications, with particular emphasis on characterizing extant materials and types of construction, and recommending treatments for continued preservation. As part of the on-site inspection, material samples were extracted for analysis and moisture readings were made of many building surfaces and substrata. This report discusses the results of the moisture measurements, with related preliminary thoughts and observations.

1. Overall Conduct of the Site Survey

After a general orientation to the site, we began by making a visual survey of the exterior walls of the fort, beginning at Ochoa Bastion and progressing westerly along the sea-exposed walls, finally to those facing the dry moat. All exterior walls were inspected. Interior walls, roofs and special features such as stairs and sentry boxes were also included in the visual survey. Equipment used to enhance the visual survey included a 200mm telephoto lens; a Protimeter MK2 moisture meter was employed for recording moisture levels present at each of the various types of masonry encountered, from outer surfaces to a depth of eight inches. In general all surfaces from where specific measurements were taken were directly accessible without the use of ladders or similar equipment, determined at the onset of this trip to be too labor-intensive or time-consuming.

In order to increase the efficiency of gathering information, work on-site began early in the morning and continued until around mid-day, at which time we conducted research in the Park library and archives at San Cristobal. In late afternoon, when the weather was again cooler, we returned to El Morro. This process turned out to be very beneficial and enlightening, as much of the material discovered in the Park files shed light in a timely way on questions or concerns leading from the site investigations.

2. General Observations

A. At first glance, the stone walls of El Morro appear in good condition; they are not. What appears to be stone surface is actually a crust that has formed, which seems very impermeable. Moisture readings taken of such surfaces show levels relatively similar to later Portland cement patches of c.1890's-1940's. This crust may be gypsum, formed as the product of a reaction between the lime of the early stuccoes and a sulfurous environment, or it may be another material. In any case, it is creating serious problems within the walls by trapping excess moisture. Specific results noted included saturated stone within the walls that, when extracted, had the consistency of oatmeal; excess moisture is also providing an inviting environment for growth of vegetation. In fact, patterns of vegetation growth were found to relate directly to the edges of this crust (and the Portland patches), where internal moisture collected as water in the process of escaping from behind the wall surfaces.

B. Moisture readings were useful as a relative measure of some characteristics of the masonry, such a permeability. In general, consistent measurements were made revealing that the lowest levels of surface moisture (5-40%) were found on the crust and the Portland patches, as stated above; mid-range levels of 25-75% were recorded on the cast composite stone installed by the U.S. Army. Highest readings of 90-100%--considered at this time to be preferable--were found on the extant stuccoes dating from the late 18th to early 19th centuries, as well as on the cement-lime patches that the Park has been applying recently. All subsurface readings, from depths of 1/4 inch to eight inches below the surface, read 100%.

C. Distinct patterns also were revealed via the moisture readings:
(1) On any given surface, readings were relatively drier at the centers than at the edges, and lower edges were relatively drier than upper edges. This apparently correlates to the movement and evaporation of internal moisture.
(2) Vegetation grows most heavily along upper edges of impermeable surfaces. It does not grow nearly as heavily or consistently on the more permeable surfaces.
(3) Not surprisingly, rings of efflorescence were noted around the edges of impermeable surfaces, indicating substantial salt deposits left after moisture escaped from behind surfaces and then evaporated.

D. Moisture--keeping it out, and getting it out once it has penetrated the walls--is a very key issue. While no major structural damage was noted during the survey, it is very probable that, given the high concentrations of moisture seen within the walls, problems may be developing undetected: If interior stone is saturated, it may be losing cohesion and strength; infill may be sloughing away, or simply compacting, and no longer providing adequate support for upper walls; hydrostatic pressure may be increasing at lower wall levels. It is clear that water penetration into walls must be significantly reduced, preferably eliminated, and that excess moisture already present within walls be allowed the means to escape without imposing threats to the stability of the structure.

E. Relative readings among masonry materials remained consistent regardless of orientation/exposure. Protected surfaces, however, were generally in better states of preservation than exposed ones, although not markedly so.

F. Archival photographs revealed that deterioration of El Morro's wall surfaces may be in an accelerated state. In some areas, most notably in the Lighthouse and on walls facing the dry moat, surface loss has been occurring extremely rapidly since just the 1960's.

3. Recommendations and Areas of Further Study

As mentioned, treating moisture is the principal concern related to masonry preservation. Based on site observations and related research, the preliminary recommendation is to restucco the outer walls. The stucco material should match the performance characteristics, not necessarily the composition, of the extant 18th and 19th century stuccoes, which appear to be very compatible with the stone substrate. Because their lime constiuent may be adversely affected by the environment, and thus forming a deleterious crust, it may be preferable to develop a new recipe calling for little or no lime. If so, other additives, such as air entraining agents, may need to be prescribed in order to attain desired levels of performance. Merlins should be restuccoed first, as a first defense against water penetration, followed by the embrasures, and then down walls in horizontal bands. This process also would allow the walls a chance to dry out a little and stabilize before being completely recoated.

Along with the analysis of mortar samples already planned, samples of the crust should be analyzed to determine whether they are in fact gypsum, or whether they contain calcium-sulfur compounds that would indicate that a chemical reaction is occurring.

Finally, it is recommended that further monitoring be done of the moisture levels deep within the walls. The results of such monitoring could yield very important information regarding the levles, collection and movement of moisture within walls. This information would then be integrated into the final preservation recommendations. Monitors would be placed at a few select locations, one each at the top, middle and lower levels of the walls. The monitors could be placed in protected batteries, such as Mercado, to decrease the risk of vandalism, which is a concern of the Park.

Please let me know if you would like to discuss further any of the above, or if I can provide additional information.

Walter Sedovic

BLAINE 8/1/89

FYI

-Joan.

ARVIN
CALSPAN CORPORATION
FRANKLIN RESEARCH CENTER
Valley Forge Corporate Center 2600 Monroe Blvd. Norristown PA 19403 215-666-3000

July 27, 1989

Mr. Walter Sedovic AIA
Historical Architect
United States Department of the Interior
North Atlantic Historic Preservation Center
26 Wall Street
New York, NY 10005

Subject: Analysis of Crust, Historic Stucco
El Morro, San Juan, PR

Reference: P.O. PX1811-9-0033
FRC Project P799-0001

Dear Mr. Sedovic:

In accordance with your request, an analysis was conducted to identify elements on the external surface and in the interior of stucco samples from the El Morro site. This report documents results which were verbally reported to you previously.

The X-ray spectrum from the clean interior (obtained by fracturing the sample) is in Figure 1. Silicon (Si) and Calcium (Ca) are the only elements (in addition to oxygen and other elements with low atomic numbers (less than 9), which are not detected by the energy dispersive X-ray technique utilized). In contrast, the spectrum in Figure 2 from a dirty area on the surface of a sample indicates the presence of many other elements and a much higher relative amount of Si, possibly from pickup of silicate (i.e., fine sand). In particular, there was a high concentration of sulfur (S), as you postulated in your letter.

Significant amounts of chlorine (Cl) and iron (Fe) were also present. The elemental analysis does not indicate how the elements, including sulphur, are incorporated into the original stucco.

I would welcome any questions concerning this analysis.

Very truly yours,

Laurence Leonard

Laurence Leonard
Principal Engineer

LL/ih
1771C
Enclosure: Figures 1 and 2.

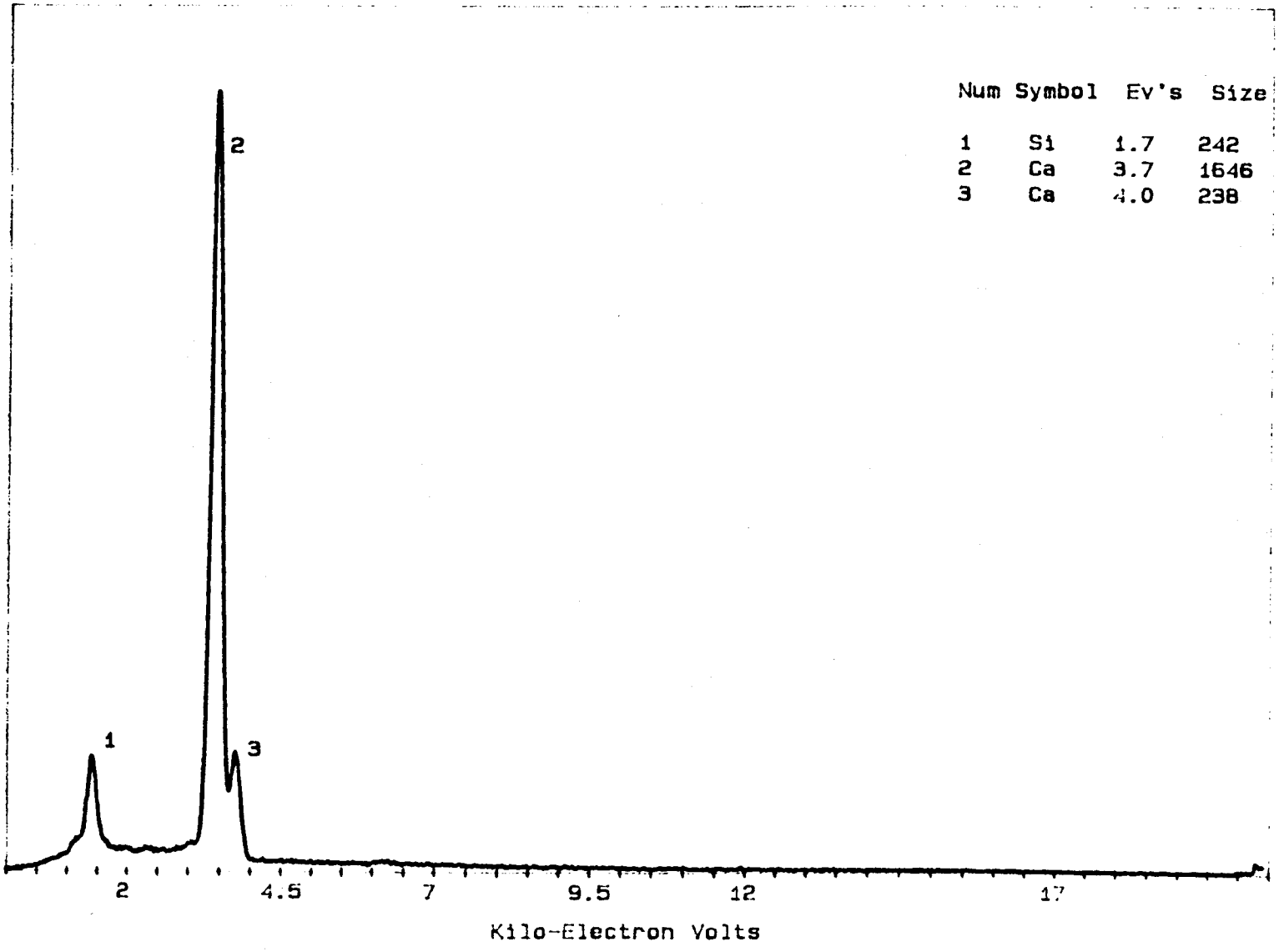

Figure 1. X-ray Spectrum from the clean interior of a piece of stucco (obtained by fracturing a sample).

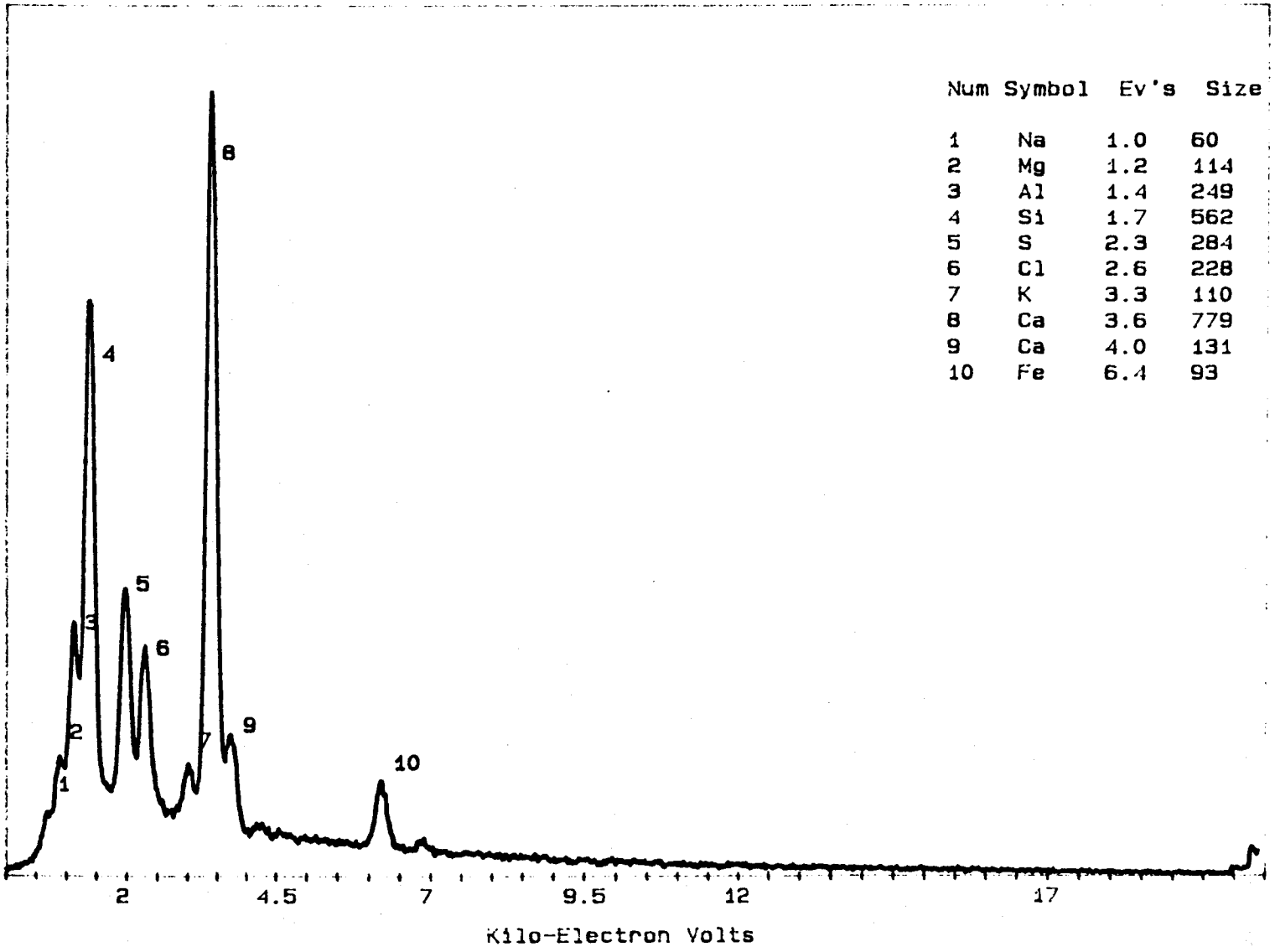

Figure 2. X-ray spectrum from the darkened surface of a stucco sample.

APPENDIX G.

Archeological Investigations at the Flanking Battery Wall of El Morro, San Juan, Puerto Rico

ARCHEOLOGICAL INVESTIGATIONS AT THE FLANKING BATTERY WALL OF EL MORRO, SAN JUAN, PUERTO RICO

By

Ken Wild

Southeast Archeological Center
National Park Service
Tallahassee, Florida

January 1991

ABSTRACT

The Southeast Archeological Center conducted archeological investigations at the fortress San Felipe del Morro, San Juan, Puerto Rico from May 8 through May 29, 1990. These investigations were designed to provide information about various construction phases of the fortress. This information was needed to complete an overall historic research study aimed at defining and identifying the growth and modifications made to the fortress since its construction by the Spanish in 1539.

This report describes these investigations and their results. The relationships between the archeological findings discussed here and the historic research conducted on El Morro are detailed in the Historic Structural Report (Cliver 1991).

MANAGEMENT SUMMARY

Archeological investigations were conducted during May of 1990 by the Southeast Archeological Center along the Flanking Battery wall within the dry moat of El Morro. The investigation were designed to locate evidence of a ca. 1602 orillon, and provide determinations on the probability that the orillon had been filled and the moat and walls of the fort had been raised during reconstruction in the 1770s.

The investigations located the corner of the ca. 1602 orillon 12.7 meters from the curtain wall at 1.15 meters below the present surface. The location of the orillon attested to the accuracy of the 1742 drawing of the fort, thereby, allowing for further comparative studies on the ca. 1773 reconstruction.

This early hornwork was used as a foundation for the battered wall. The corner of the orillon consisted of four vertical stones and a footer stone. Butted against the orillon is a rubble wall that filled the orillon in the ca. 1773 reconstruction. The fact that the battered wall is built atop the filled orillon confirmed that the battered walls presently in view were constructed in the late 18th century. Excavation of the soils adjacent to the rubble wall indicated that the moat was filled 2.8 meters during the ca. 1773 reconstruction. Analysis of the materials and methods used during these two construction phases assisted in determining the age of other areas of the fortress and the reuse of earlier materials.

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INTRODUCTION

While Historic Architect Blaine Cliver and staff conducted research and mapped San Felipe del Morro for a historic structures report, several hypotheses were developed that required testing through archeological methods. It was felt that these excavations could provide information on structural renovations made to the fort about 1773. A 1742 drawing of the fortress, produced in Spain, depicts a recessed area, (orillon) in the flanking wall of Austria Bastion that is not present today (Figures 1, 2 and 3). The orillon would have allowed riflemen to enfilade the curtain wall and entrance to the fort. The orillon was constructed or reconstructed between 1602 and the 1620s from the hornwork remains left by the attack and capture of the fortress by the Earl of Cumberland in 1598.

Drawings of the fort produced after the ca. 1773 refurbishing of El Morro indicated that the orillon was filled during this period. It was furthered hypothesized from the studies and previous archeological research (Smith 1962) that the moat level as well as the walls may have been raised as much as 10 feet or three meters during the ca.1773 reconstruction. If the moat had been filled, as suspected, then the construction seam of the orillon where it was filled, if it existed, would be underground.

While conducting the analysis and study of the ca. 1773 reconstruction of the fort, it was suspected that much of the same materials and techniques were used in both the 17th and 18th centuries making it difficult to date the different periods of construction. Archeological investigations were, therefore, designed to locate evidence of the ca. 1602 orillon, determine the accuracy of the 1742 drawing, and evaluate the probability that the moat and walls of the fort had been raised during the 18th century reconstruction (Wild 1989). If the investigations located a portion of the original orillon and if the orillon was filled, then it would also be possible to differentiate between the methods and materials utilized in the two construction periods.

The investigations, therefore, were directed towards the location of a specific vertical masonry construction joint in the flanking battery wall of Austria bastion where the suspected filled orillon butted against the ca. 1602 orillon corner. From the research conducted by Blaine Cliver, Historic Architect for the project, the construction joint would be located, in the moat, approximately 34 to 40.5 feet from the junction of the curtain wall and the flanking battery wall (Figures 1 and 2).

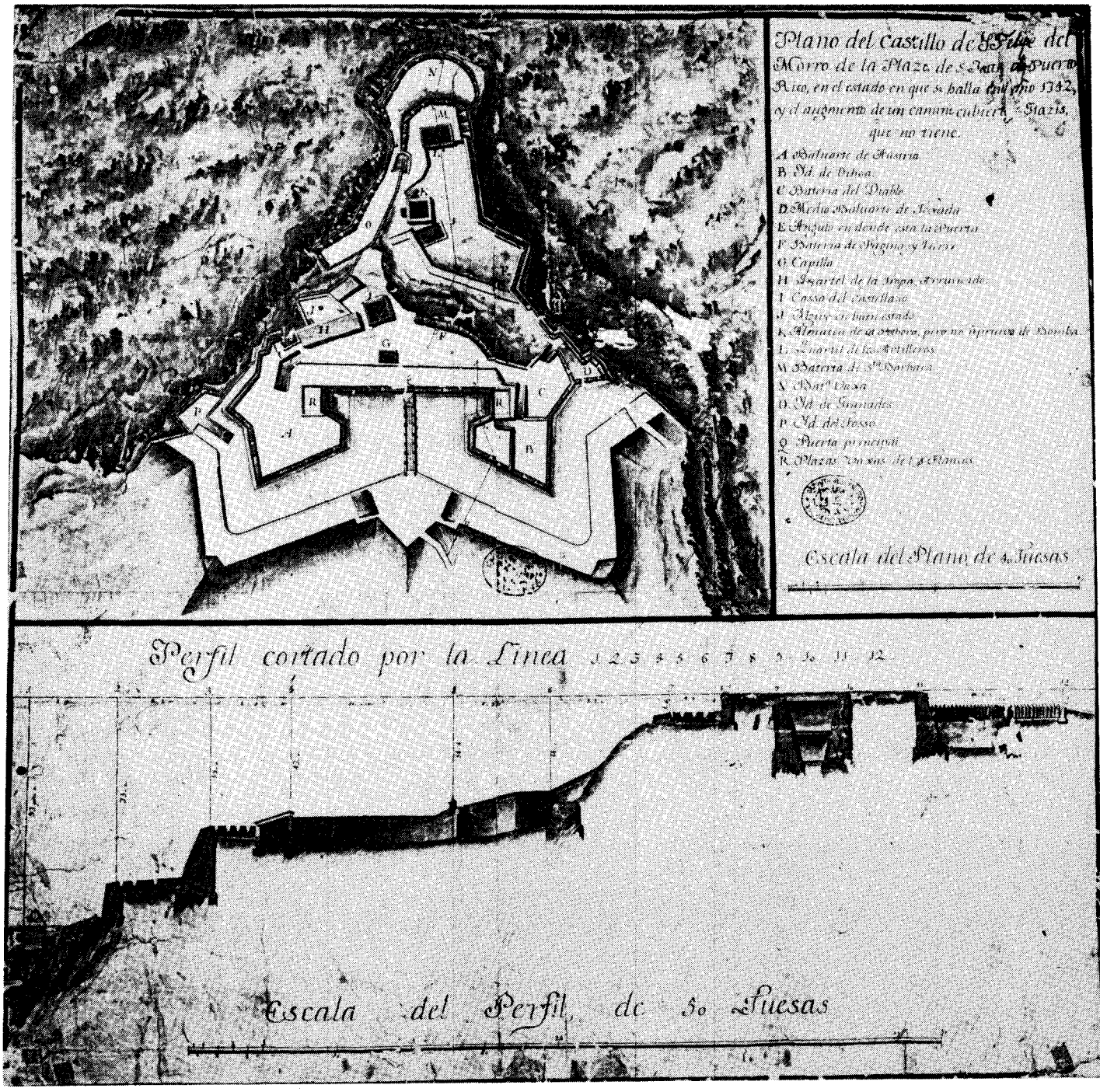


Figure 1. Plan and Section of the Castle of the San Felipe Del Morro, 1742 (Madrid).

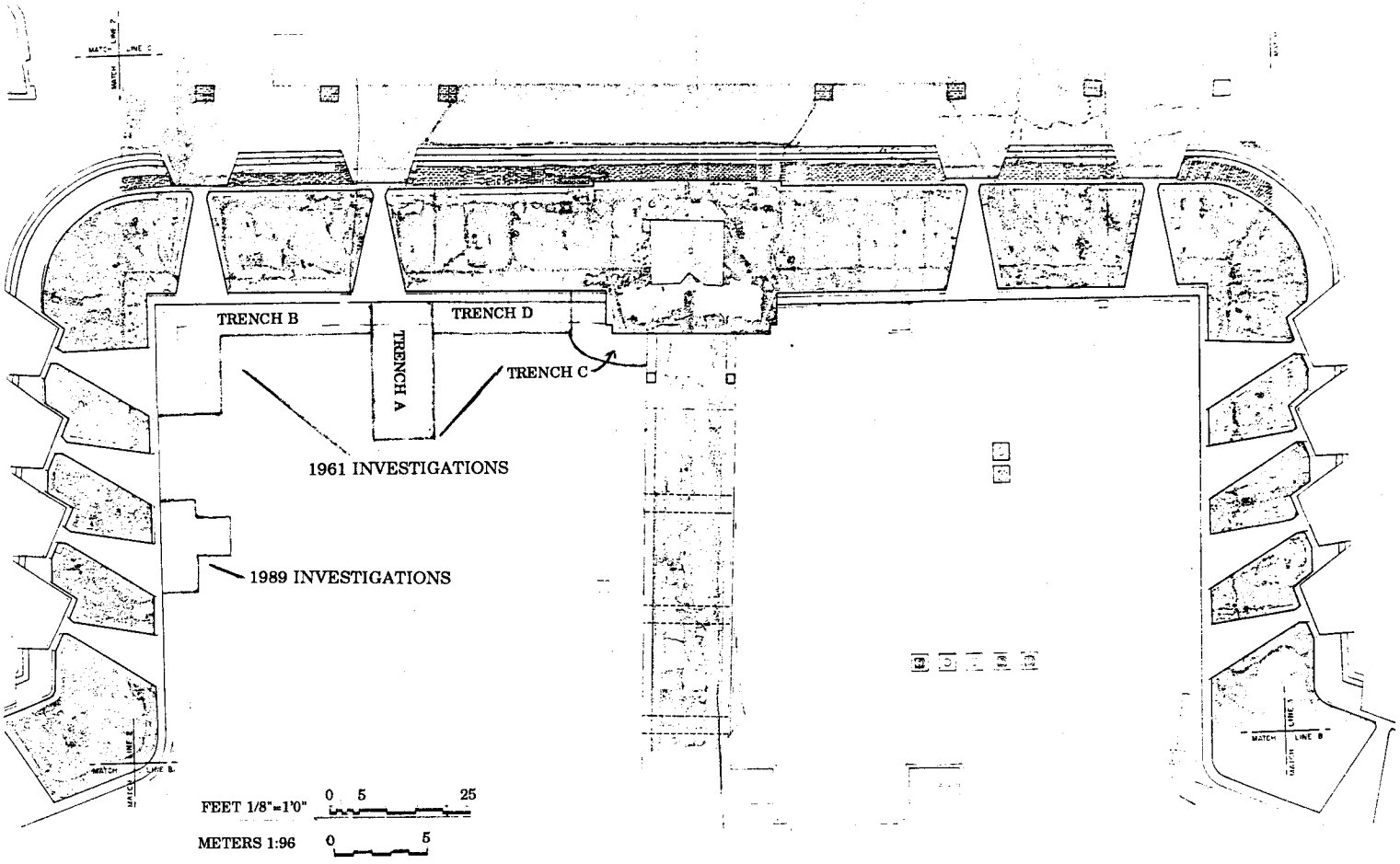


Figure 2. Location of Archeological Excavations Conducted in 1961 and 1989. Drawing Reproduced From Historic American Building Survey (Overby 1988).

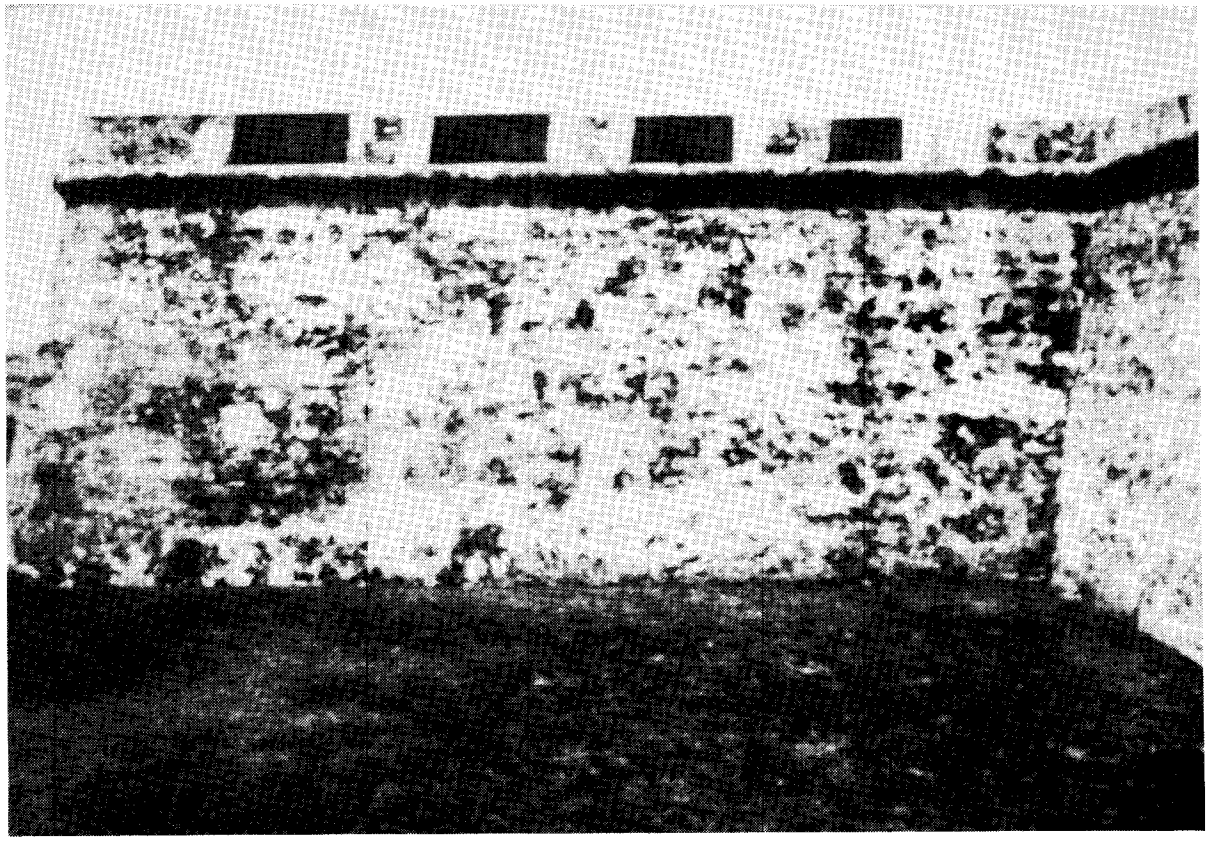


Figure 3. Photograph of the Study Area and the Flanking Battery Wall of Austria Bastion Prior to Excavation.

PREVIOUS INVESTIGATIONS

Excavations were conducted by Hale Smith in 1961 along the curtain wall and flanking wall of Austria Bastion but the investigations did not extend to the construction joint in question (Figure 2). Although the investigations in 1961 were inconclusive on the specific problems being addressed by the present historic study the archeological work by Smith did provide a basis from which to design the 1990 project. The investigations conducted by Smith (1962) along the flanking and curtain walls provided information about the various strata within the moat area. These strata included from the surface down a fill layer brought in to level the moat area for a golf course. This strata was dated to the 1940 period. Underlaying the golf course level was found another disturbed strata created for a tennis court present in 1926. Below these strata Smith encountered two thick stratum of brownish red sandy clay and yellow sand that extended to the base of the curtain wall. These strata of sand contained construction debris and cultural material that suggested to Smith the possibility that the moat had been filled at different periods after the ca. 1773 reconstruction. He concluded that a mortar level found at the base of the flanking battery wall made of mortar, sandstone chips and clay was the initial moat floor and that it remained at this level until after the ca. 1773 reconstruction (Smith 1962:21).

Smith provided a sequence of wall construction but having determined that the soils found in association with the exposed construction sequences post dated all building phases and the inability to tie anyone segment of the wall construction to a known construction phase he was only able to speculate on temporal relationships. However, in trench B at the junction of the curtain wall and the flanking battery wall Smith found a rubble wall that suggested, to the historic structures report researchers, the probability that an orillon was present and was filled during the ca. 1773 reconstruction. This could not be determined for certain because the excavations did not extend to the point where the corner of the orillon, as depicted in the 1742 drawing, would butt against the rubble fill.

The 1961 investigations also indicated that in order to reach the bottom of the fort wall excavations would have to extend to a depth of at least three meters or approximately 10 feet. Also, the soils would be loose, and safety measures such as steeping back the excavation and shoring of walls to prevent wall collapse would be necessary.

METHODOLOGY

Initially four excavation units were established in the study area. Excavation unit 1 was established along the flanking wall between points determined by Historic Architect Cliver to be the probable location of the construction joint of the filled orillon. Excavation unit 1 was located 10.4 meters from the junction of the flanking battery and curtain walls and extended two meters along the battery wall. The unit was divided in 1X2 meter sections designated 1A and 1B. A second 2X2 meter unit (unit 2) was located in front (northeast) of unit 1. Unit 2 was established for the purpose of stepping into unit 1 and, therefore, was excavated in a manner that resulted in 50X200X50 cm steps leading down into unit 1. Two more 1X2 meter excavations units (units 3 and 4) were placed on either side of unit 1. Unit 3 was located on the northwest side of unit 1 and unit 4 was located on the southeast side. Initially, units 3 and 4 were established for stepping purposes and to be excavated approximately half the distance (two meters) required to reach the wall footings or floor found by Smith in 1961. Unit 3 was excavated about half the distance, but evidence of the orillion in unit 4 resulted in excavation to 3.57 meters. The depth reached in unit 4 required an additional 5th unit for stepping back to the southeast (Figure 4).

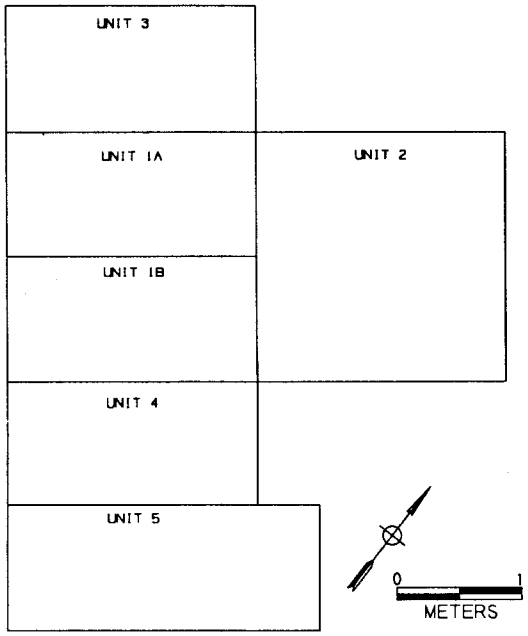


Figure 4. Plan of Excavation Units Along the Flanking Battery Wall.

Excavation was conducted in 20 cm arbitrary levels except in cases where natural stratigraphy was present or archeological features were encountered. Strata identified as modern fill zones (surface to 65 cmbs) were excavated as one feature.

Excavated materials were screened through 1/4-inch mesh hardware cloth except for the disturbed upper zones where only sample areas were screened. All artifacts and other evidence of past human activity, ecofacts, etc., were field identified, packed, and shipped to the Southeast Archeological Center for analysis. The work was documented with maps, notes, photographs, drawings, and collections.

Upon return to SEAC materials were heat sterilized as required by the Department of Agriculture to eliminate nematodes and other pests foreign to domestic soils. Materials were washed with water in closed containers as not to drain into the building septic system. Plastic containers used in the transportation of materials were boiled for at least two minutes. Other containers of cardboard or wood that may have come into contact with contaminated materials were burned. After washing, materials were air dried.

Analysis of materials began with identification of artifacts or ecofacts. Initial classification sorted materials into five basic categories of mineral, vegetal, animal, human remains, and unidentified. These were then subdivided into more specific artifact categories. This information was recorded onto forms developed for a data base analysis program. The data was then entered into the analysis program. This program allowed a variety of data manipulations. The materials were then cataloged according to the guidelines set forth in the Museum Handbook, Museum Records Part II (Zimney and Vaughn 1987). This also required the completion of a form for each catalog record generated. Cataloged records from this project will be entered into the Automated National Catalog System (ANCS).

INVESTIGATIONS

In all five units, the excavation of the first 60, and in some areas, 80 to 170 centimeters below the surface (cmbs), revealed evidence of disturbance relating to the American occupation of the fort in the 20th century. From the surface to 60 cmbs four to five layers of fill were encountered in each unit. This material was deposited for the creation of a golf course that extended into the moat during the 1940s and 50s. Smith (1962) also found these same strata throughout his excavations in the moat area. Within each of these strata were found materials dating to the golf course construction period (1940s) and artifacts dating back to the 16th, 17th, 18th and 19th centuries attesting to the mixed nature of the deposit. Materials dating to early Spanish occupation included one fragment of montelupo polychrome popular between 1500-1550 and fragments of El Morro ware dated between 1550-1770 (Deagan 1987). Two coins were recovered that date to between 1516-1550 (Figure 5). The coins are 4 maravedies minted in Santo Domingo to honor Carlos and Juana also Carolus at Ioanna (Ortega 1982).

Seventeenth century materials included metropolitan slipware (manufactured between 1630-1660) and delftwares. Ceramics of the 18th century included creamwares popular between 1762-1820 and astbury ware used ca. 1725-50. Artifacts representative of the 19th century included: a wide variety of pearlware type ceramics (1780-1840), canton porcelain (1800-1830), ginger beer bottle fragments (1820-1930), and a variety of whiteware type ceramics (1820-1900), (Hume 1982). Objects dated to the 20th century included wire nails, a pen, molded clear bottle glass, and amber beer bottle glass. Other diagnostic artifacts recovered from this fill zone included: various buttons of shell and bone, and military brass buttons (Figure 6), a French gun flints (Figure 7), wrought nails and spikes, and percussion caps and a brass primer pin for a percussion type gun (Figure 8). A complete list of material types and the provenience from which they were recovered is on file at the Southeast Archeological Center, Tallahassee, Florida.

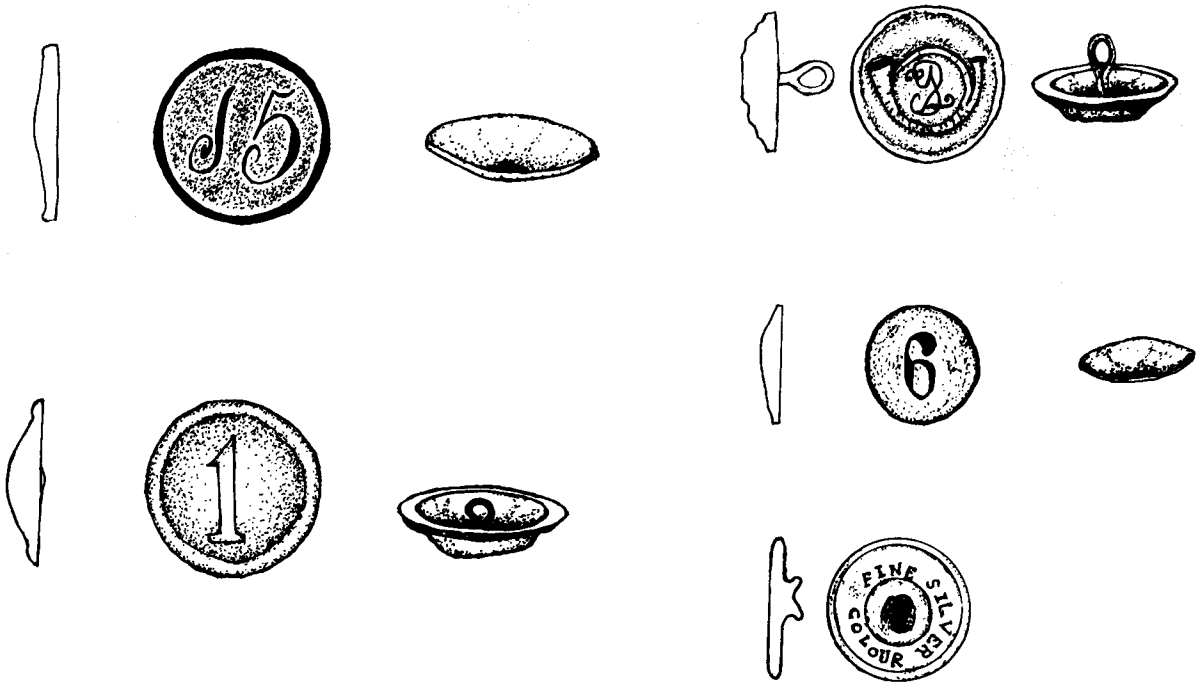
A sketch drawing of the fort made in the 1930s depicted a tennis court in the immediate vicinity of the excavation. During the 1961 investigations Smith found remains of this tennis court which he notes was of concrete and was present in the area in 1926. Evidence for the tennis court during the 1990 project was found in the form of concrete curbing underlaid with a red clay stratum. The red clay stratum was identified by Smith (1962) as the base for the tennis court. The curbing was found 1.4-1.5 meters out from the fort wall at 40-60 cmbs. The curbing runs parallel to the flanking battery wall. Four connecting sections of the curbing extended across units 3, 1, 4, and 5. A discarded section of the curbing was also removed from unit 2 (Figure 9). A footer was located adjacent to the curbing in unit 4 that initially was

thought to be for the tennis net post (Figure 10). The footer was of concrete and apparently set in a bucket. Continued excavation in unit 4, below the footer, revealed

a midden deposit of 20th century trash. This deposit extended to a depth of 1.70 meters (Figure 11). The majority of diagnostic materials recovered from the midden dated to the 1940s suggesting that the footer was not for the tennis court but for another function required in the 1940s.

Actual Size

Figure 5. Two Brass Coins Minted in Santo Domingo Between 1516-1550.



Actual Size

Figure 6. Brass Military Buttons.

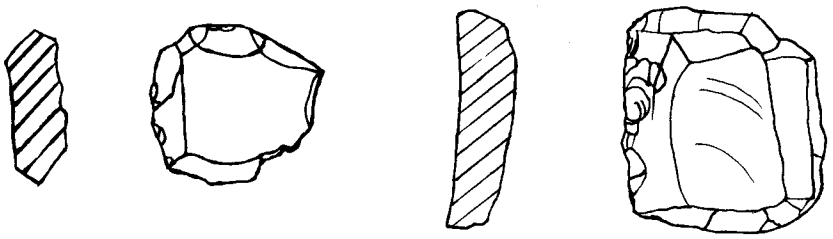


Figure 7. French Gun Flints.

Actual Size

Figure 8. Brass Primer Pin for a Percussion Gun.

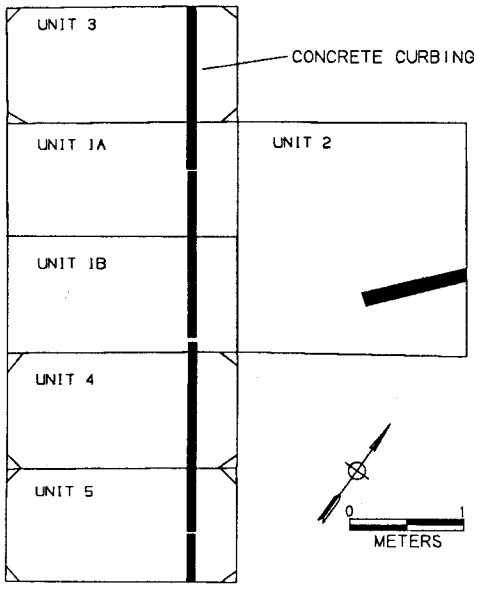


Figure 9. Location of Concrete Curbing in Units 1 through 5.

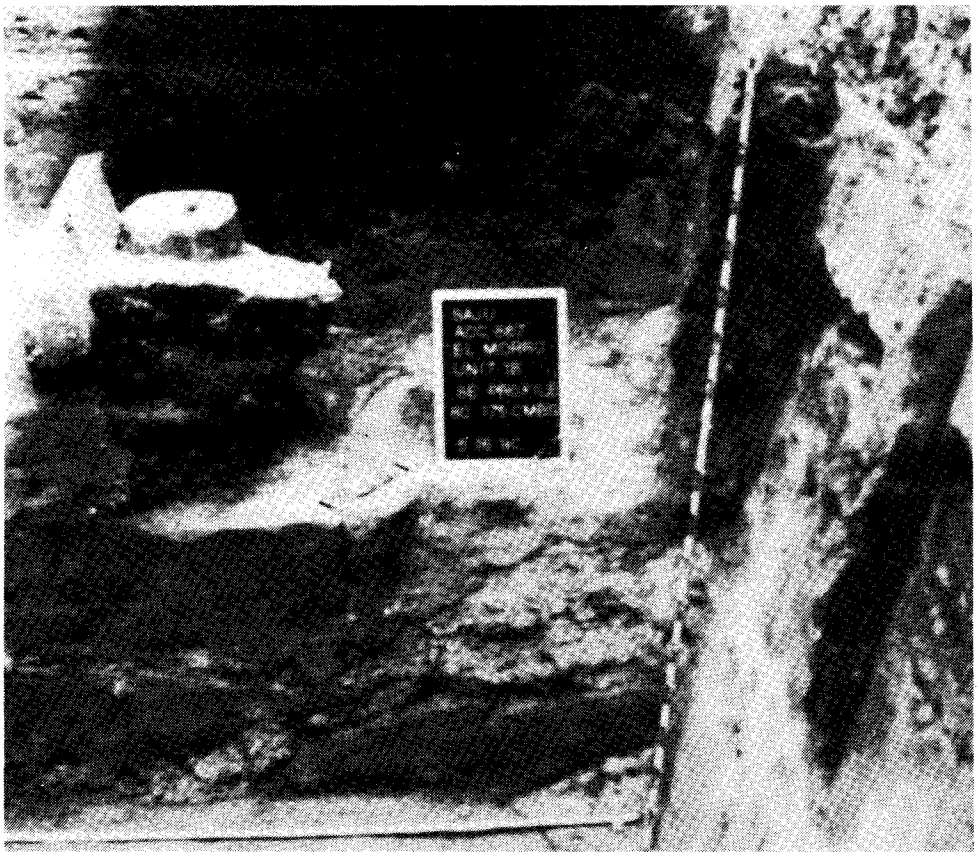
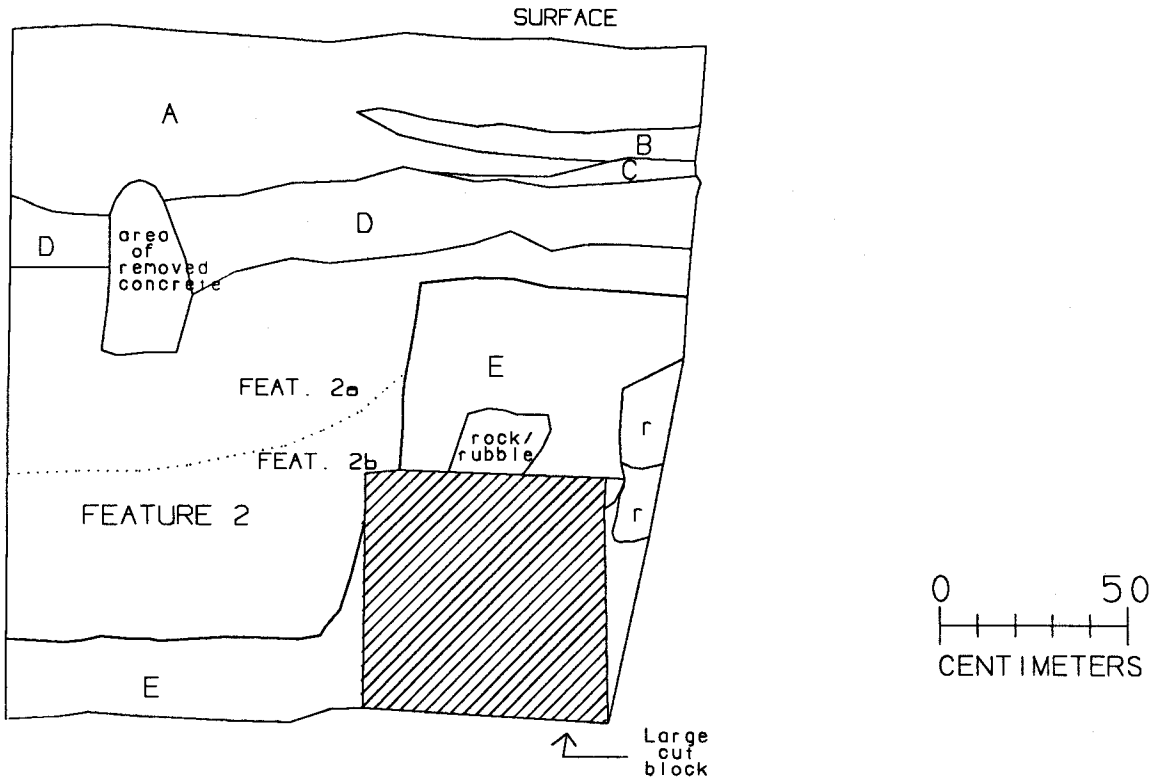


Figure 10. Concrete Footer Located in Unit 4.



Zone A: 5YR3/4 dar reddish brown clayey sand with 5YR5/8 yellowish red clay. white mortar included and heavy artifact concentration.

Zone B: 5YR3/4 dark reddish brown clayey sand mixed with chunks of 5YR5/8 yellowish red clay.

Zone C: 7.5YR4/6 strong brown sand mixed with 5YR3/4 dark reddish brown clayey sand. clay pieces and small bits of mortar included.

Zone D: 7.5YR4/2 dark brown sand grading to 5YR3/4 dark reddish brown clayey sand mixed with 5YR5/8 yellowish red clay. brick. mortar rubble. and artifact concentration.

Zone E: 10YR5/6 yellowish brown sand.

Feat. 2a: 7.5YR5/6 strong brown sand mixed with 10YR6/8 brownish yellow sand and 7.5YR4/6 strong brown silty sand and 7.5YR4/2 dark brown clayey sand with some mortar and shell. heavy artifact concentration.

Feat. 2b: 7.5YR4/2 dark brown clayey sand mixed with 10YR5/6 yellowish brown sand and 7.5YR5/6 strong brown sand . very heavy artifact concentration.

r = rock

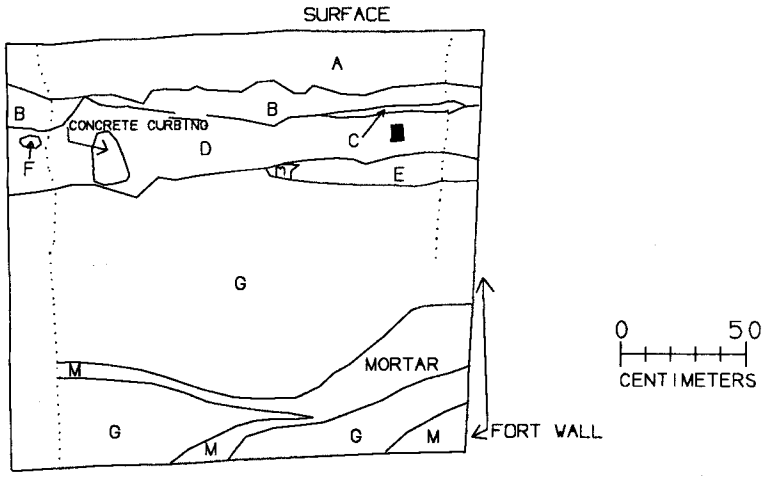
Figure 11. Feature 2 as Shown in the Southeast Profile of Unit 4 as Excavated to a Depth of 1.8 Meters Below the Surface.

The majority of datable objects recovered from the trash deposit were bottles. Many of these bottles had embossed on the base the Owens Company trade mark and a date of 1941. Some of the bottles were intended for distilled spirits and soft drink beverages; some were embossed with the Puerto Rican town names of Arecibo and Ponce. Other objects recovered included a U.S. penny dated 1940, light bulb fragments, wire mesh for screening, plastic, and wire nails. These 20th century materials were mixed with 18th and 19th century ceramics of creamware, pearlwares and fragments of chinaware indicating that the same soils used to fill for the golf course were also used to fill the hole dug for the trash deposit. In unit 1A and 3 another 1940s pit was located adjacent to the fort wall that extended to a depth of approximately 100 cmbs. This pit also contained materials dated to the 20th century as well as the 18th and 19th centuries.

The excavation of these upper strata revealed, along the flanking battery wall, one course of dressed stone, just below the surface, that the Historic Architect identified as patch work that was undertaken by the U.S. Army during its occupation of the fort. Just below this patch work a deteriorated mortar masonry joint that is approximately ten centimeters thick was noted. Below this masonry joint dressed stone continued.

As the excavations continued below 60-65 cmbs, the soils became somewhat more uniform except in units 4 and 5 where the ca. 1940 trash pit was located. Throughout units 1A, 1B, 2 and 3 the soils changed dramatically below 60-65 cmbs to a strong brown (7.5YR 5/6 to 4/6) loose sand mixed with sandstone and mortar fragments. These soils continued to the bottom of excavation in units 1A, 1B, 2, and 3. These sandy soils were also recorded in units 4 and 5 between the fort wall and feature 2 and below the trash pit. Excavation of this loose sandy stratum revealed concentrated deposits of mortar typical of debris deposited during wall construction. The mortar deposits extended out from the flanking battery wall at a downward slope and became thinner away from the wall (Figures 12, 13 and 14).

The number and variety of artifacts recovered from this stratum decreased considerably compared to the disturbed levels above. Most of the materials recovered below the golf and tennis court fill were ceramics, of which the majority were non-diagnostic course earthenwares. The diagnostic materials recovered demonstrated that these soils were deposited in the later half of the 18th century. All diagnostic artifacts recovered have a beginning manufacturing date before or starting in the 18th century and all but one (Ichtucknee blue on white majolica, ca. 1600-1650) were still being produced in the 18th century. Materials recovered included: faience (ca. 1600-1802), slipware (ca. 1580-1795), unidentified majolica fragments (ca. 1490-1850), olive jars of the early (ca. 1500-1800) and middle style (ca. 1580-1800) and plain creamware (ca. 1762-1820). Pearlware ceramic types were recovered from the upper 20 to 30 centimeters of this deep deposit. The fact that pearlwares were



Zone A: 7.5YR3/2 dark brown silty sand mixed with 5YR4/6 yellowish red clay. lots of small shell and artifacts.

Zone B: 5YR5/6 yellowish red clay layered with 7.5YR3/4 dark brown silty sand.

Zone C: 7.5YR5/6 strong brown sand mixed with 5YR3/2 dark reddish sandy clay.

Zone D: 7.5YR3/4 dark brown silty sand spotted with 7.5YR4/4 brown sand. lots of brick and mortar, building rubble.

Zone E: 7.5YR4/6 strong brown sandy clay mixed with 7.5YR5/8 strong brown sand and 7.5YR3/4 silty sand. mortar and aggregate present.

Zone F: 7.5YR4/6 strong brown sand.

Zone G: 7.5YR5/6 strong brown sand with some aggregate.

Zone M: mortar and plaster mixed with 7.5YR5/6 strong brown sand.

■ = brick

Figure 12. Unit 1B Southeast Profile.

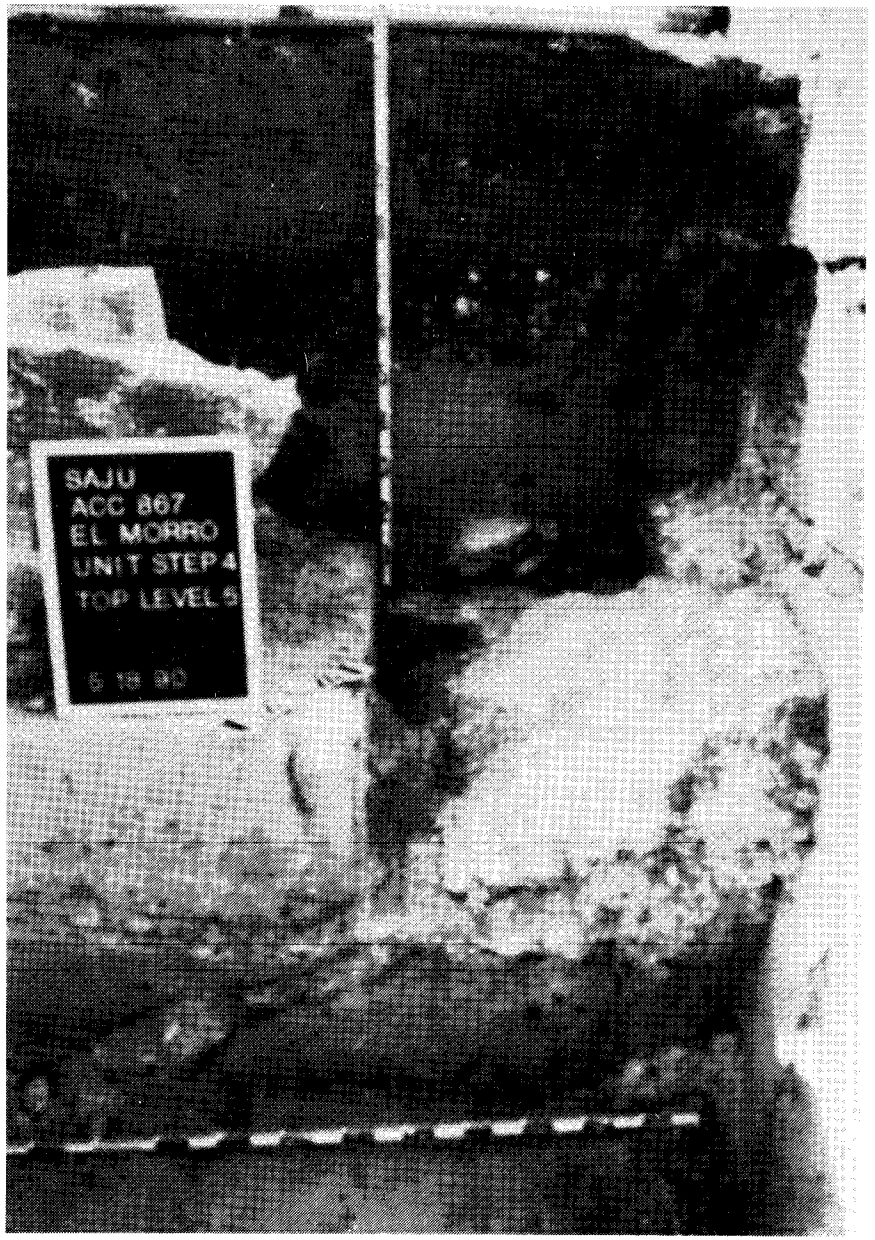
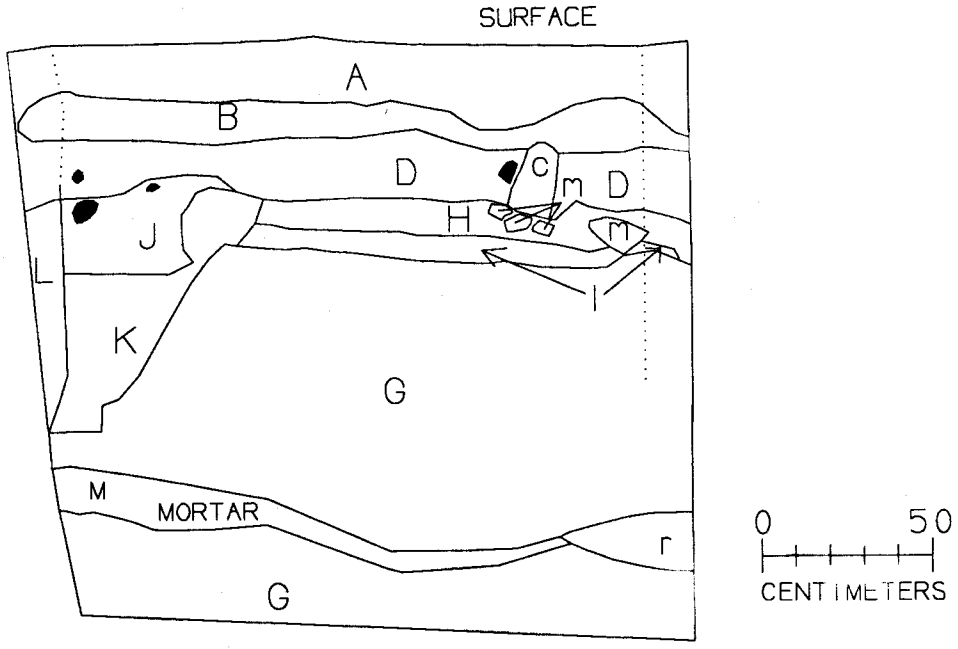


Figure 13. Photograph of Exposed Construction Mortar Debris in Unit 4.



Zone A: 7.5YR3/2 dark brown silty sand mixed with some 5YR4/6 yellowish red clay. many small shells and artifacts.
Zone B: 5YR5/6 yellowish red clay layered with 7.5YR3/4 dark brown silty sand.
zone D: 7.5YR3/4 dark brown silty sand spotted with 7.5YR4/4 brown sand. lots of brick and mortar.
Zone G: 7.5YR5/6 strong brown sand. some aggregate pieces.
Zone H: 5YR5/8 yellowish red sandy clay mixed with 5YR4/6 yellowish red sandy clay with mortar dust mixed in and mortar pieces throughout.
Zone I: 5YR4/6 yellowish red clayey sand mixed with 5YR5/8 yellowish red sandy clay with heavy mortar and brick throughout.
Zone J: 10YR4/3 dark brown clayey sand mottled with 10YR3/3 dark brown clayey silt and 10YR4/4 dark yellowish brown silty sand and 10YR5/6 yellowish brown sand with brick and mortar pieces.
Zone K: Brick and mortar mixed with 7.5YR4/6 strong brown sand. mixed with 10YR5/6 yellowish brown sand.
Zone L: 10YR5/6 yellowish brown silty sand grading to 10YR5/8 yellowish brown silty sand with a few small pieces of brick and mortar.
Zone M: mortar and plaster mixed with 7.5YR5/6 strong brown sand.

c = concrete curbing
r = rock
m = mortar
■ = brick

Figure 14. Unit 1A Northwest Profile.

not manufactured until 1780 suggests either the surface of this sandy deposit was exposed for a period of time or construction was not completed in this area until after 1780.

The excavation of the sandy soils from units 1A, 1B, 2, and 3 revealed, along the flanking battery wall, a change from dressed battered stone to a rough irregular rubble stone and a red clayey mortar fill. The change was recorded at 1.95 meters below the surface. This rubble wall extended out from the dressed stone wall approximately eight centimeters and continued downward at approximately the same scarp as the dressed stone wall above.

Excavation reached the base of the rubble stone wall in the southeastern quarter of unit 1B at 3.25 meters below the surface (Figure 15). At the base of the wall two parallel courses of brick were located; the bricks were attached to the rubble stone wall and laid with their long axis to the wall (Figure 16). Three courses of the bricks were recorded. Whole bricks measured 28 cm long, 10 cm wide and five cm thick. A prepared level of mortar and sandstone was also found in association with the courses of brick. This mortar and sandstone level sloped away from the brick to 3.36 meters below the surface. The last 50 centimeters of soils atop this mortar floor were divided into three zones (A, B, and C) according to color and texture (Figure 16). Within zone C 11 pottery sherds identified as refilmed earthenware (Smith 1962) were recovered. No date for this type of ware has been determined; however, the recovery of brick fragments identical to those used along the base of the rubble wall indicated that these redfilmed sherds were deposited during the later half of the 18th century. Smith (1962) had also located this prepared floor and brick courses at the base of his excavations along the flanking battery wall. He excavated a portion of the floor and found it to be approximately 12 centimeters thick.

At 1.15 meters below the surface in unit 4 a large stone was encountered that altered the course of the investigations (Figure 11). After consultation with the Historic Architect it was decided that excavations be shifted in order that the deepest point reached in the excavation be located adjacent to this stone. The stones horizontal angle suggested that it was the corner of the orillon as it was identical to the angle depicted in the 1742 drawing of the fort (Figures 1, 15 and 17). Excavation down along the southeast edge of the stone revealed a vertical wall of solid construction consisting of five stones laid without batter or scarp on any exposed sides. It was obvious that this vertical stone wall had been constructed at a different date than the battered wall of dressed stone and the rubble stone wall (Figures 18 and 19).

These construction differences and the vertical joint dividing these construction units were what was anticipated if the orillon existed and had been filled (Figure 20). The rubble stone wall filled the orillon during the ca. 1773 reconstruction and the unbattered stone wall is the original corner of the orillon that was constructed in ca. 1602.

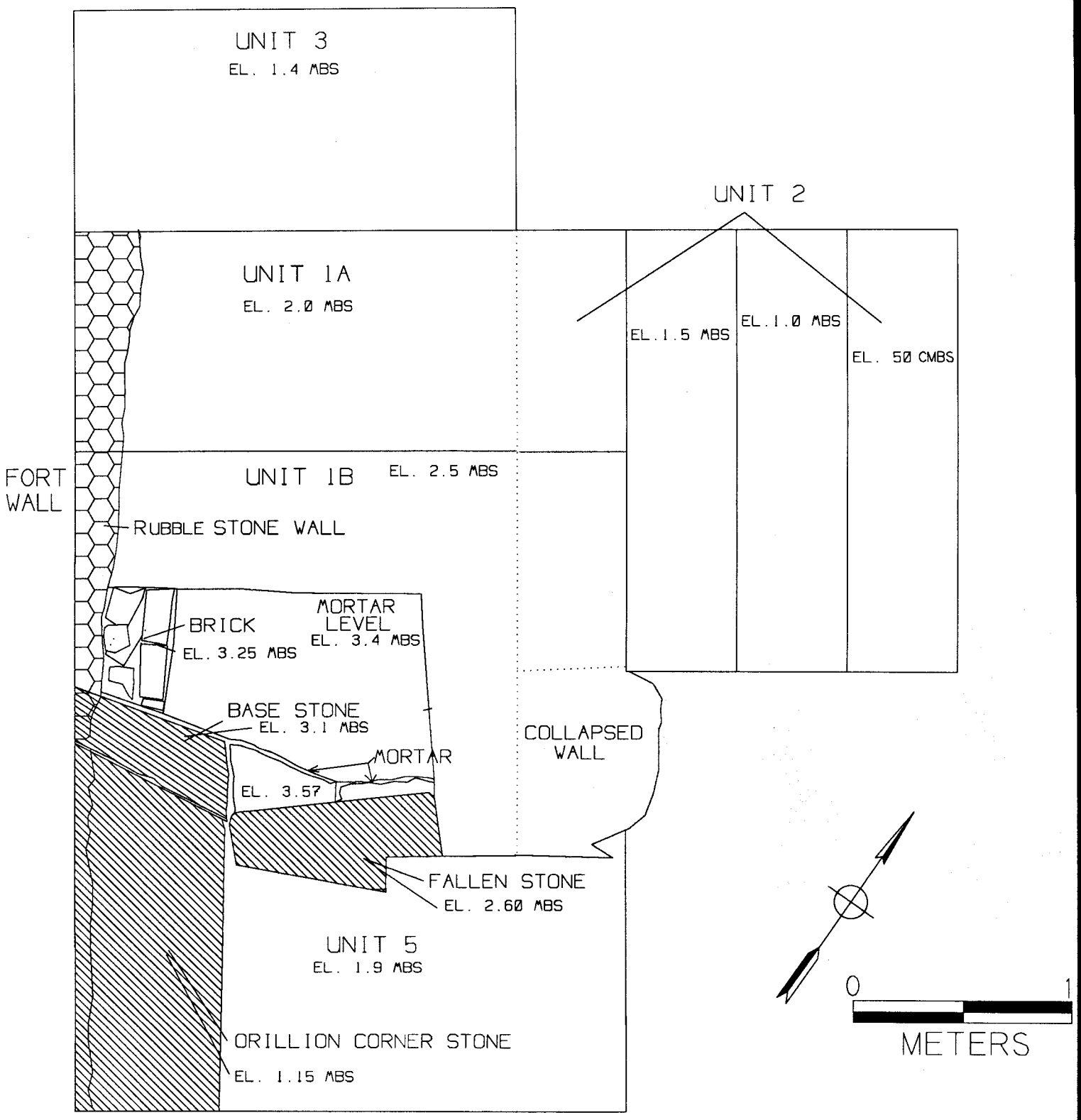
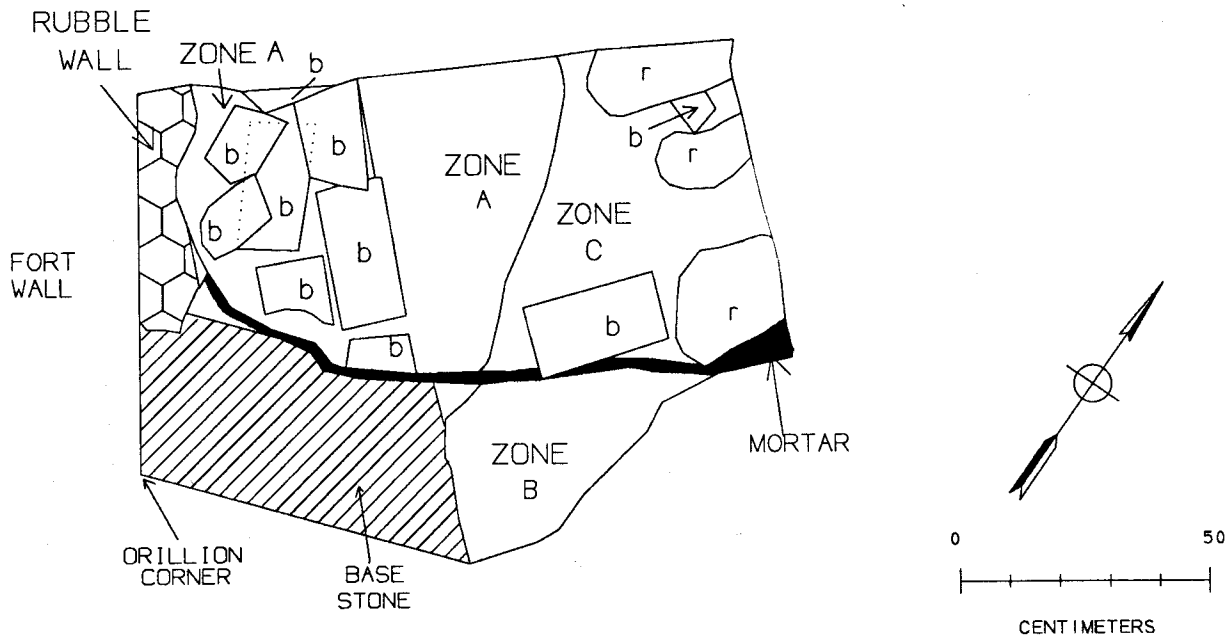


Figure 15. Plan View of Excavated Area.



ZONE A: Yellow sand with no aggregate. Possible trench containing large bricks.

ZONE B: Yellowish brown sand with mortar and brick rubble. Separated from A and C by ridge of mortar.

ZONE C: Dark Brown sand with artifacts and less building rubble.

b = BRICK

r = ROCK

Figure 16. Plan View Near the Base of Excavations in Unit 4.

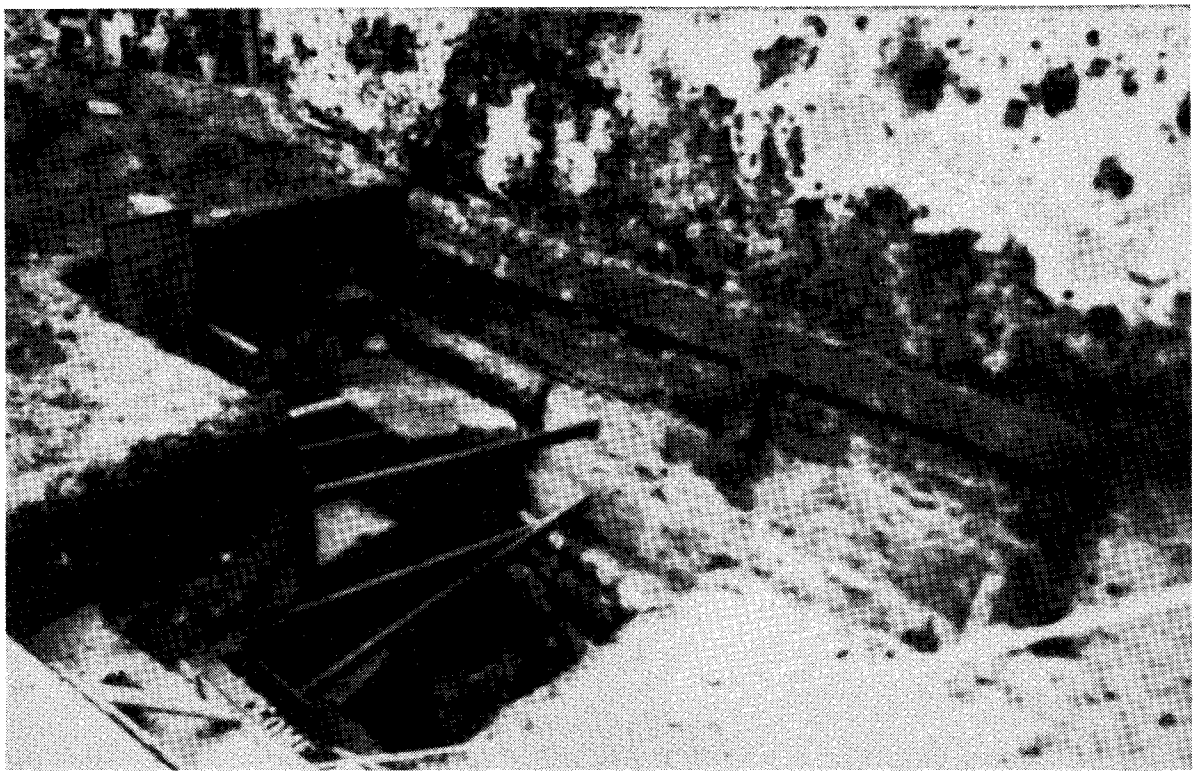


Figure 17. Photograph of the Excavated Area.

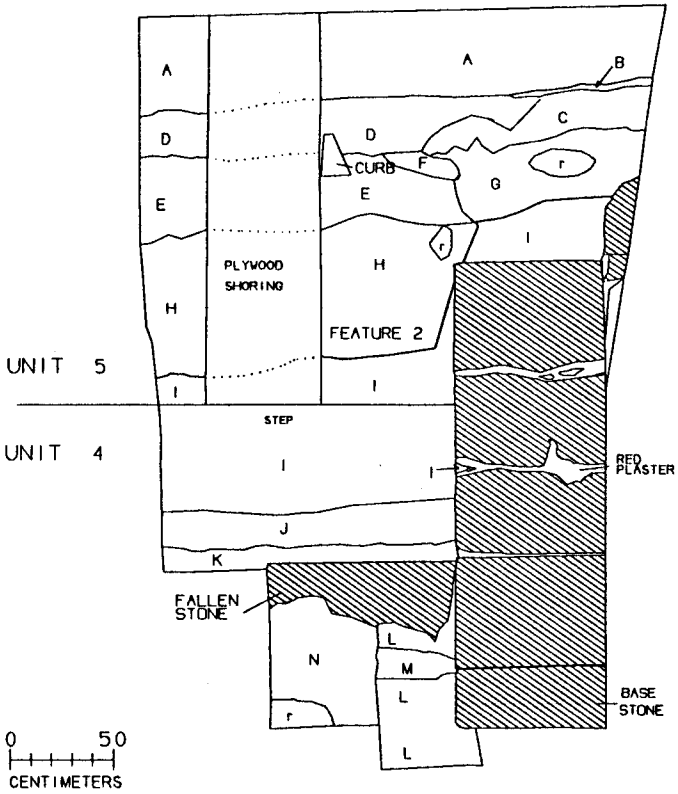


Figure 18. Units 4 and 5, Southeast Profile with Rubble Stone Wall and Mortar Level.

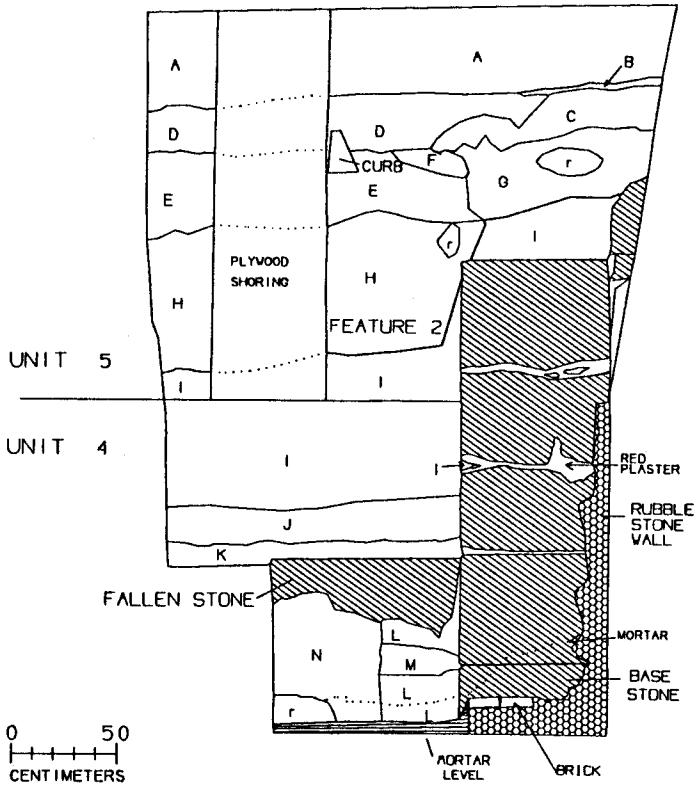


Figure 19. Units 4 and 5, Southeast Profile Showing Unbattered Wall.

ZONE A: 5YR3/4 dark reddish brown clayey sand mixed with 5YR5/8 yellowish red clay with chunks of white mortar and a heavy concentration of artifacts.

ZONE B: 5YR3/4 dark reddish brown clayey sand mixed with chunks of 5YR5/8 yellowish red clay.

ZONE C: 5YR3/4 dark reddish brown clayey sand mottled with 5YR5/8 yellowish red clay, 5Y8/1 white mortar, 2.5YR5/8 red brick, 7.5YR4/0 dark gray sand, with heavy artifact concentration.

ZONE D: 5YR3/4 dark reddish brown clayey sand mixed with 5YR4/2 dark reddish gray fine sand.

ZONE E: 10YR5/8 yellowish brown sand mottled with a few 10YR8/1 white chunks of mortar.

ZONE F: 7.5YR3/4 dark brown sandy soil mottled with a few 7.5YR8/1 white chunks of mortar and mixed with 10YR5/8 yellowish brown sand.

ZONE G: 7.5YR5/8 strong brown sand mixed with 7.5YR4/0 dark gray sand and mottled with 7.5YR8/1 white chunks of mortar and small to large rocks. Rubble fill zone.

ZONE H: Feature 2. 7.5YR5/8 strong brown sand mixed with 7.5YR3/4 dark brown sandy soil and 7.5YR4/0 dark gray sand.

ZONE I: 10YR6/4 light yellowish brown sand with small amount of 2.5YR5/8 decayed red brick.

ZONE J: 10YR8/4 light yellowish brown sand with concentration of 2.5YR5/8 decayed red brick. Zone has layered appearance.

ZONE K: 5YR4/6 reddish brown coarse sandy clay mixed with 5YR8/1 white mortar and a few 2.5YR5/8 red brick fragments.

ZONE L: 7.5YR5/8 strong brown coarse sand with no aggregate.

ZONE M: 7.5YR5/4 brown sand mixed with 7.5YR8/4 pink mortar and lots of aggregate.

ZONE N: 7.5YR5/6 strong brown sand mottled with chunks of 7.5YR4/4 dark brown clay.

r = ROCK

Key to Figures 18 and 19.

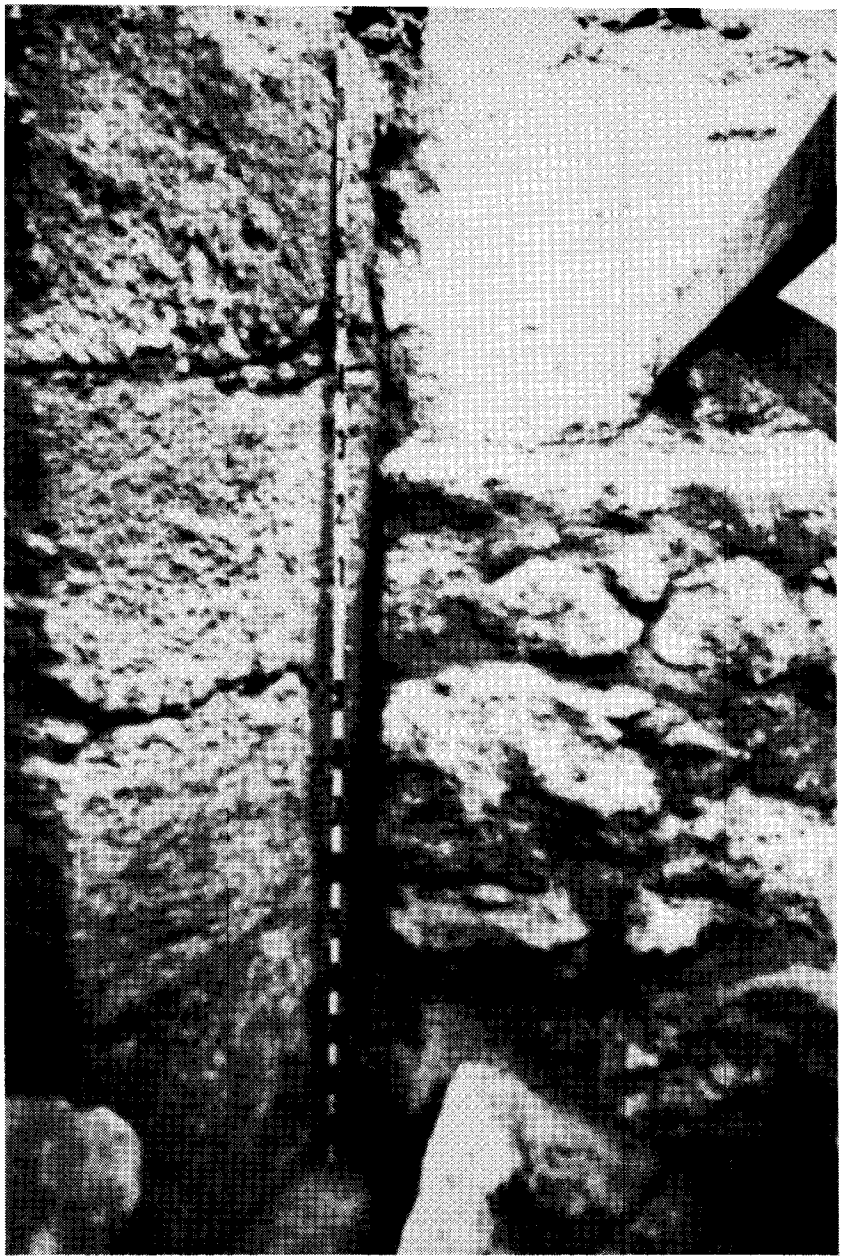


Figure 20. Photograph of the Construction Seam Between the ca. 1602 Orillon Corner and the Filled Orillon Area.

The stones of the vertical wall are 70 cm wide and between 40 and 45 cm thick except for a base stone which is 30 cm thick. The base stone extends out 30 cm from beneath the upper stones to the northwest providing a footing. The length of the stones was not determined as they continued beyond the width of the excavation (Figure 15).

As discussed, the soils in the northeast half of units 4 and 5 and adjacent to the vertical stone wall were disturbed by Feature 2 down to a depth of 1.70 meters. Below Feature 2 the same loose sandy soils similar to those found below 60-65 cmbs in the other four units was encountered. The soils below Feature 2, however, were a light yellowish brown (10YR 6/4) with patches of decayed red brick (stratum K, figures 18 and 19). Below the yellowish brown soil a stratum of coarse reddish brown (5YR 4/6) sand mixed with white mortar and brick fragments was encountered atop a fallen building stone. Few diagnostic artifacts were recovered from these two strata; however, the soils contained the white mortar fragments and sandstone identical to that used to construct the dressed stone battered wall and rubble wall dated to ca. 1770. Various strata were identified beneath the fallen stone (strata L, M, N, figures 18 and 19). No diagnostic artifacts were recovered from these strata as they were not excavated from beneath the fallen stone. A small portion of stratum L was excavated from beneath the base stone. What appeared to be a charcoal deposit was present in the strata (Figure 18). Analysis of this material by Beta Analytic, a carbon 14 dating company, unfortunately concluded that the materials could not be dated because of a lack of carbon.

RESULTS

In relationship to the overall study of El Morro, the 1990 archeological investigations confirmed the architectural accuracy of the 1742 drawing and provided information on the horizontal and particularly the vertical scales used in the drawing. These determinations allowed comparative studies that resulted in the understanding of the evolutionary changes the fortress has undergone (Cliver 1991).

Specifically the investigations concluded that the moat level immediately after the ca. 1773 reconstruction was approximately 60 to 70 cm below the present surface (Figure 17). This conclusion was drawn from the presence of the U.S. Army stone patch work located just below the present surface, from wall areas that had been plastered, and from the golf course fill, The location of the top remains of the ca. 1602 orillon corner at 1.15 meters below the surface indicated that the earlier hornwork had not been built upon but was torn down five to six meters to a point 60 to 70 cm below the ca. 1773 moat level. Having determined that the rubble orillon fill was post ca. 1770 prompted a reexamination of Smith's findings along the curtain wall. Smith exposed at 60 cmbs a vertical stone wall identical in construction and materials as the orillon corner (Figure 21). It was concluded that this vertical stone wall along the curtain wall also dated to ca. 1602 and construction of the present battered wall began at a depth of 60 cm below the present surface.

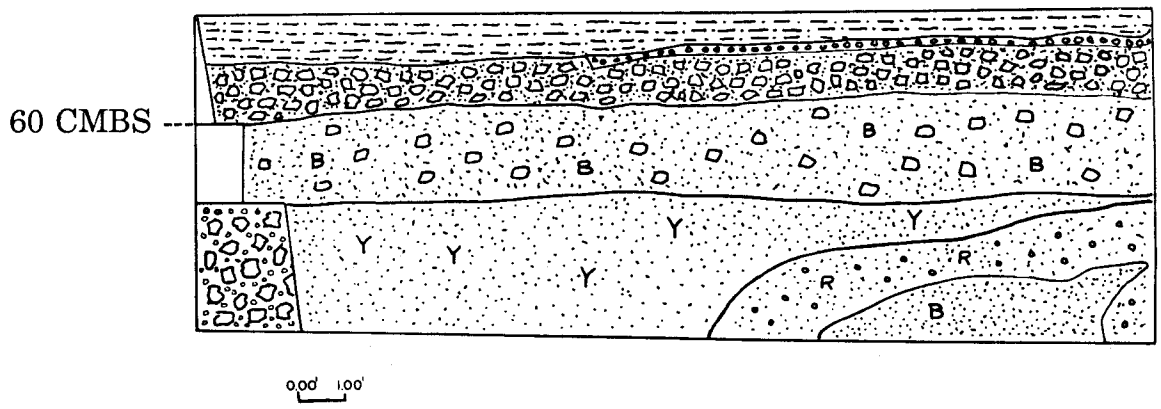


Figure 21. Northeast Profile of Trench A Located Along the Curtain Wall as Excavated in 1961 (Smith 1962).

Along the flanking battery wall, however, the ca. 1602 hornwork was used as foundation for the present battered wall. It occurred at the same depth (1.95 cmbs) as the rubble wall used to fill the orillon. The orillon was filled to the curtain wall as this rubble construction was located by Smith in 1960 at the juncture of the curtain wall and the flanking battery. In that the rubble wall, ca. 1773, was also used as foundation for the battered wall confirms that the walls presently in view above grade, within the moat area, were constructed in the late 18th century and constructed to a point at which the terreplein of the bastion is now 3.5 meters above the remains of the ca. 1602 level. Excavation of the soils adjacent to the rubble wall indicated that the moat was filled 2.8 meters during the ca. 1773 reconstruction and not after the reconstruction was completed as had been indicated in previous investigations. The lack of a surface finish to the face of the orillon fill indicates the likely intent of filling the moat from the onset of construction in ca. 1773. The brick courses and mortar level located at the base of the rubble wall were attached to the rubble wall and the mortar used was of the same materials as used in the rubble wall. These features, therefore, were determined to be the footing for the rubble wall and not the moat floor as had been suggested (Smith 1962). The footing course at the base of the orillon corner was assumed to be the level of the original orillon floor.

Further analysis of the excavated materials, and methods used in the construction phases aided in determining the age of other sections of the fort and demonstrated that materials from earlier construction periods were reused (Cliver 1991).

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APPENDIX H.

Mortar Analysis, San Cristóbal

Mortar Analysis, San Cristóbal

conducted by

Historic Preservation Center,
North Atlantic Regional Office,
National Park Service

and

Center for Preservation Research,
Columbia University

1988

Please note that the work represented in the following mortar analysis was conducted early in the investigation of the site. Findings from later mortar investigations were not compatible with findings of this appendix. Further integration of analysis data should be carried out. All data from mortar and analysis is available at the Building Conservation Branch of the Cultural Resource Center, NARO, Boston, MA.

MORTAR

Objective

The objective of mortar analysis work at San Cristobal was to determine the characteristic types of mortar used during the six major periods of construction. These periods were defined as follows:

I. 1625 - 1765

II. 1765 - 1809

III. 1809 - 1837

IV. 1837 - 1868

V. 1868 - 1898

VI. 1898 - 1987

Definitions

For the purposes of this study, "mortar" was divided into three categories: mortar, stucco, and plaster. "Mortar" is here defined to be a material used in masonry construction (such as in laying bricks or stones). "Stucco" is an exterior surfacing material. "Plaster" is an interior surfacing material. The Troops' Quarters, for example, was built using masonry and mortar. It was later covered on the outside with stucco and the interior rooms were finished with plaster. These definitions are modern and do not necessarily reflect historical usage at San Cristobal.

Methodology

Samples of mortar, stucco, and plaster were extracted at the

Period I

8 samples total

Type A - 3 samples

Plaster - 1 sample (shells)

Stucco - 2 samples (shells)

Type C - 5 samples

Mortar - 5 samples

All samples are lime mortars. All type A samples contain rod-shaped skeletons (possibly a type of sea shell). All type C samples contain brick dust.

Period II

47 samples total

Type A - 3 samples

Stucco - 2 samples (1 with shells)

Mortar - 1 sample

Type B - 25 samples

Plaster - 13 samples (7 with shells)

Stucco - 4 samples (2 with shells)

Mortar - 8 samples (3 with shells)

Type C - 18 samples

Stucco - 6 samples

Mortar - 12 samples

All samples are lime mortars. Approximately half of the type A and type B samples contain sea shells. All type C samples contain brick dust.

Period III

2 samples total

Type A - 1 sample, stucco

Type B - 1 sample, plaster

Both samples are lime mortars with characteristic white medium grain quartz sand. No sea shells were observed.

Period IV

1 sample, Type C - mortar

Period V

8 samples total

Type B - 3 samples
Plaster - 1 sample
Stucco - 2 samples (1 natural cement)

Type C - 3 samples

Mortar - 3 samples

Type D - 2 samples

Plaster - 1 sample (Portland cement)

Mortar - 1 sample (Portland cement)

Samples are a mix of lime mortars and cements. No sea shells were observed. All type C samples contain brick dust. All type D samples contain Portland cement.

Periods V or VI (exact period unknown)

2 samples total

Periods V or VI (cont'd)

Type D - 2 samples

Plaster - 1 sample (Portland cement)

Mortar - 1 sample (Portland cement)

Both samples contain Portland cement.

Period VI

6 samples total

Type A - 1 sample, stucco (Portland cement)

Type B - 5 samples

Plaster - 1 sample

Stucco - 2 samples (1 Natural cement)

Mortar - 2 samples

Samples appear to be a mix of both lime mortars and cements.

Later Unknown (after Period II)

13 samples

Type B - 7 samples

Type C - 5 samples

Type E - 1 sample

Dates and categories of specific mortar samples are summarized on the following page. Mortar analysis results, grouped by unit, are included at the end of this appendix.

SAJU: Mortar Samples Distribution Summary

Period	Type	Plaster	Stucco	Mortar
I	A	T-1 m02	03 m01, 11 m3b	
	C			T-m03, T-1 m04, T-4 m3b,
				11 m3a, 11 m04
II	A		16 m01, 16 m07	15 m04
	B	T-1 m01, T-2 m01, T-2 m02	02 m01, 02 m02, 02 m07,	T-1 m05, T-1 m06, T-2 m03,
		T-2 m04, T-2 m05, T-4 m01,	03 m06	T-3 m01, T-3 m2a,
		T-4 m02, T-4 m3a, 02 m12		03 m08, 03 m12, 09 m03
		09 m04, 09 m05, 15 m2b,		
		16 m05		
	C		02 m06, 03 m02, 03 m07	03 m05, 03 m17, 09 m02
			03 m09, 03 m10, 09 m10	09 m07, 15 m01, 15 m2a,
				15 m03, 15 m07, 16 m02,
				16 m06, 16 m08, 16 m10
III	A		03 m16	
	B	02 m13		
IV	C			02 m08
V	B	15 m06	15 m05, 16 m11	
	C			03 m04, 03 m11, 16 m09
	D	16 m04		16 m03
V-VI	D	09 m06		09 m09
VI	A		09 m11	
	B	11 m02	02 m05, 09 m08	03 m15, 11 m01
UNKNOWNS	B	02 m03	02 m04, 02 m11, 03 m03	02 m10, 03 m18
			03 m13	
	C	T-3 m2b	16 m14	02 m09, 16 m12, 16 m13
	E		09 m01	

Conclusions

In general, the following conclusions may be drawn based on the analysis of eighty-six (86) mortar samples from San Cristobal and review of the historical documentation.

Lime mortars appear to have been used in periods I, II, and III. Lime mortars and hydraulic mortars (mortars that can set under water) were used in periods V and VI.

Type C (red-orange) mortars, found used in periods I, II, IV, and V, all contain brick dust. Use of brick dust mortars in the 18th and early 19th centuries is supported by the documentation. These mortars are easily recognized at the site by their distinctive red-orange color. None were found to contain sea shells. It is virtually impossible to date these mortars out of their contextual locations since the mixes do not appear to have changed substantially over the years. These mortars were used most commonly in masonry construction, although they also appear to have been used extensively as exterior stuccoes in period II.

Type A (white) mortars from period I are distinguished by an abundance of white rod-shaped skeletons (possibly a type of sea shell), white quartz sand, and white fines. Analysis identfied the good "lime and sand" mixture described in the documentation as a type A stucco.

Type A (white) and type B (beige) mortars from period II are characterized by containing sea shells and/or white rod-shaped skeletons in about 50% of the samples analyzed. The shells observed were both fragments and whole microscopic shells. Although the rod-shaped skeletons are similar to those seen in period I, they are not found in the same abundance in period II. Another characteristic of some of the type B plasters, stuccoes, and mortars is an exceptionally low sand percentage and a correspondingly high calcium hydroxide ($CaOH_2$) percentage. These samples do not seem to be limited to one date but rather span the years ca. 1769 - ca. 1785 based on their locations.

Type A (white) and type B (beige) mortars from period III are characterized by a distinctive medium grain white quartz sand.

The use of hydraulic mortars, such as natural and Portland cements, appears to be limited to periods V and VI. The historical documentation supports the use of hydraulic concrete in the 1890's and Portland cement in the 20th century.

MORTAR SAMPLE LOCATIONS

Unit T-1

SAJU T-1 M01	Plaster, west end of T-1 south wall (P01)
SAJU T-1 M02	Plaster, Dungeon east wall beneath ship drawings
SAJU T-1 M03	Mortar, original north wall of the castle as sampled from the Dungeon, east side of doorway
SAJU T-1 M04	Mortar, Dungeon ceiling
SAJU T-1 M05	Mortar, Dungeon south wall
SAJU T-1 M06	Mortar, dripped from ceiling onto floor at Dungeon south end

MORTAR SAMPLE LOCATIONS

Unit T-1

Plan is detail of 1769 plan by O'Daly (shading added to illustrate existing works in 1765).

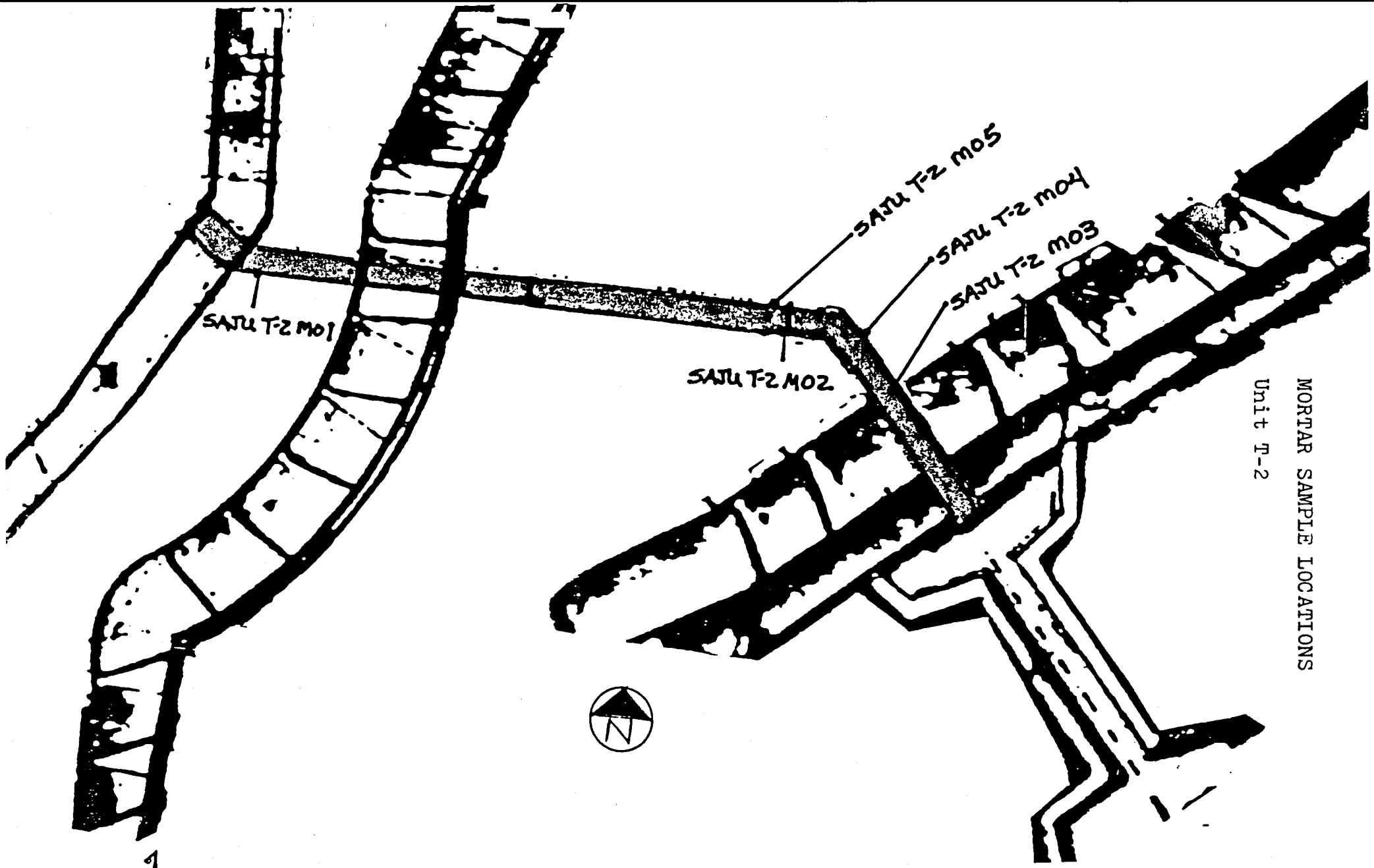
MORTAR ANALYSIS: SAJU T-1

SAMPLE T-1	m01	m02	m03	m04	m05	m06
TYPE	Plaster	Plaster	Mortar	Mortar	Mortar	Mortar
CLASS	B	A	C	C	B	B
PERIOD	II	I	I	I	II	II
% SAND	40	51	60	52	58	53
& FINES	8	9	11	9	4	8
% $CaOH_2$	52	40	29	39	38	40
SAND P/V	33	47	50	44	45	48
LIME P/V	58	45	32	44	43	44
CEMENT P/V						
FINES COLOR	10 YR 8/2	[WHITE]	[orange]	[orange]	10 YR 7/3	10 YR 7/3
SHELL	yes	yes				

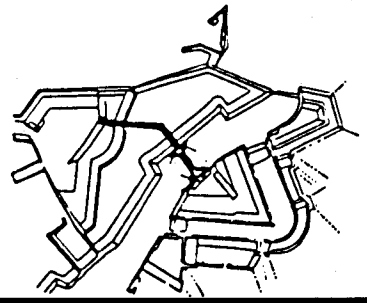
MORTAR SAMPLE LOCATIONS

Unit T-2

SAJU T-2 M01	Plaster, T-2 south wall near Plaza
SAJU T-2 M02	Plaster, lower south wall near postern (graffiti dated 1865 and 1871)
SAJU T-2 M03	Mortar, cut stone mortar joint at postern (P01)
SAJU T-2 M04	Plaster, north wall near postern
SAJU T-2 M05	Plaster, north wall at mid T-2



MORTAR SAMPLE LOCATIONS
Unit T-2



Plan is detail of 1769 plan by O'Daly.

MORTAR ANALYSIS: SAJU T-2

SAMPLE T-2	m01	m02	m03	m04	m05				
TYPE	Plaster	Plaster	Mortar	Plaster	Plaster				
CLASS	B	B	B	B	B				
PERIOD	II	II	II	II	II				
% SAND	9	24	23	38	38				
& FINES	2	18	3	5	4				
% $CaOH_2$	90	58	73	57	58				
SAND P/V	7	32	21	30	31				
LIME P/V	100	65	82	60	65				
CEMENT P/V									
FINES COLOR	10YR 7/4	[WHITE]	7.5YR 7/4	10YR 7/4	10YR 8/2-3				
SHELL									

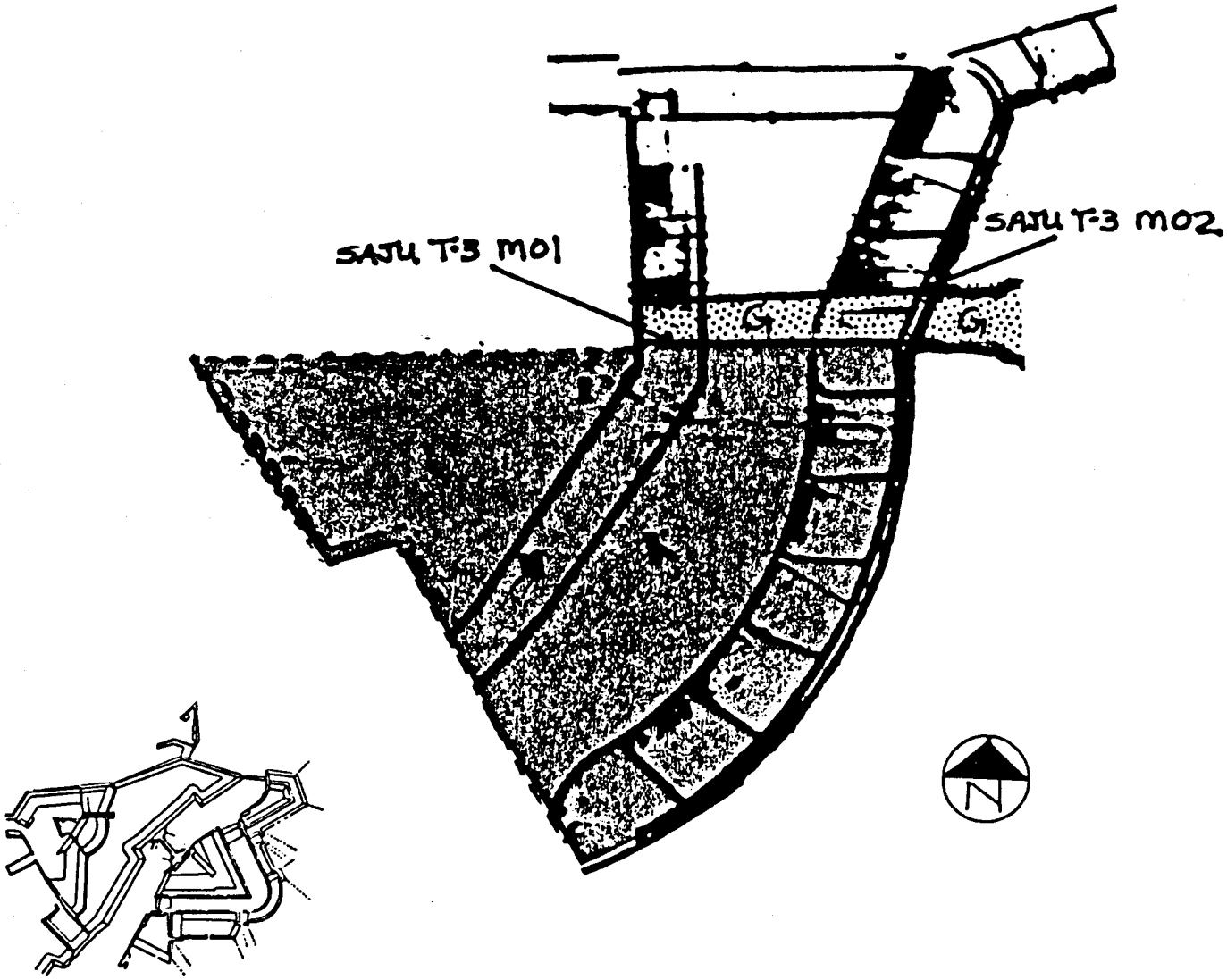
MORTAR SAMPLE LOCATIONS

Unit T-3

SAJU T-3 M01	Mortar, south wall
SAJU T-3 M02a	Mortar, cut stonework at east end of T-3, north wall
SAJU T-3 M02b	Plaster, applied above M02a (P01)

MORTAR SAMPLE LOCATIONS

Unit T-3



Plan is detail of 1769 plan by O'Daly (shading added to show location of original 17th century Caballero).

MORTAR ANALYSIS: SAJU T-3

SAMPLE T-3	m01	m02a	m02b						
TYPE	Mortar	Mortar	Plaster						
CLASS	B	B	C						
PERIOD	II	II	After II (unknown date)						
% SAND	37	36	32						
& FINES	0	5	18						
% $CaOH_2$	63	60	50						
SAND P/V	23	28	50						
LIME P/V	69	68	56						
CEMENT P/V									
FINES COLOR	10 YR 6/4	10 YR 6/4	5 YR 6/6						
SHELL	YES	YES							

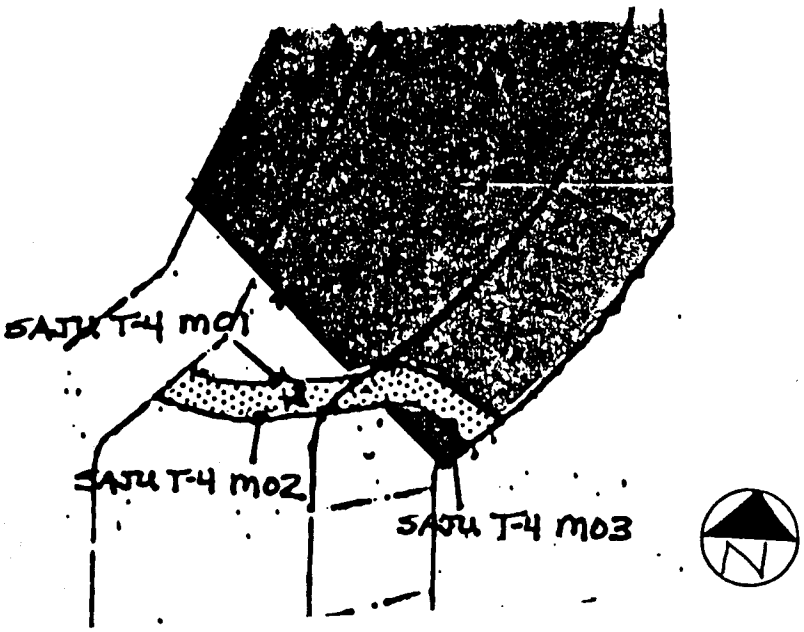
MORTAR SAMPLE LOCATIONS

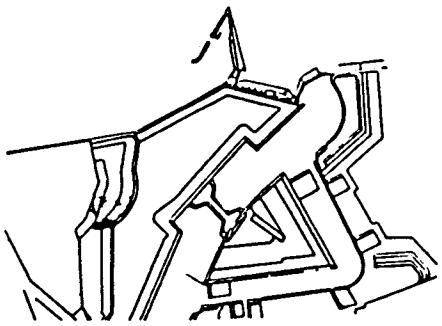
Unit T-4

SAJU T-4 M01	Plaster, north wall
SAJU T-4 M02	Plaster, south wall (next to "1773" graffiti) (P01)
SAJU T-4 M03a	Plaster, south wall at east end of T-4
SAJU T-4 M03b	Mortar, south wall east end beneath M03a

MORTAR SAMPLE LOCATIONS

Unit T-4





Plan is detail of original 1773 plan by O'Daly (shading added to show location of original 17th century Caballero).

MORTAR ANALYSIS: SAJU T-4

SAMPLE T-4	m01	m02	m03a	m03b					
TYPE	Plaster	Plaster	Plaster	Mortar					
CLASS	B	B	B	C					
PERIOD	II	II	II	I					
% SAND	34	24	21	36					
& FINES	9	7	9	5					
% $CaOH_2$	57	70	71	59					
SAND P/V	31	20	21	29					
LIME P/V	64	79	80	66					
CEMENT P/V									
FINES COLOR	10 YR 7-8/2	10 YR 7/3	10 YR 6/4	5 YR 5-6/6					
SHELL	YES	YES							

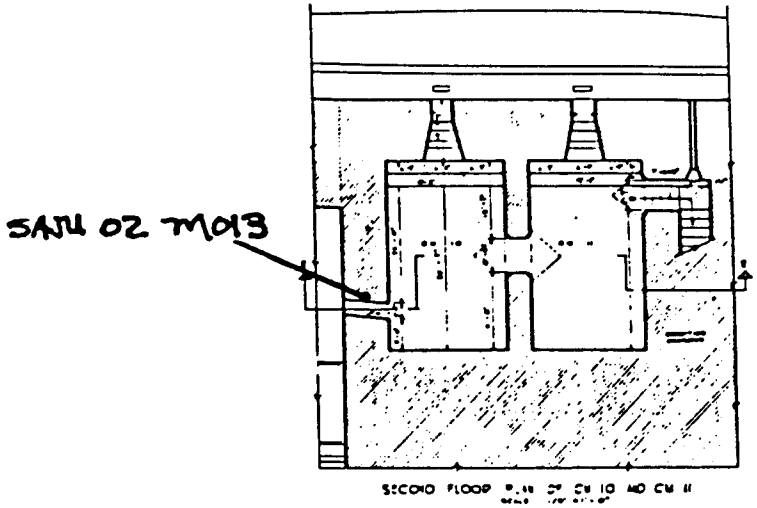
MORTAR SAMPLE LOCATIONS

Unit 02

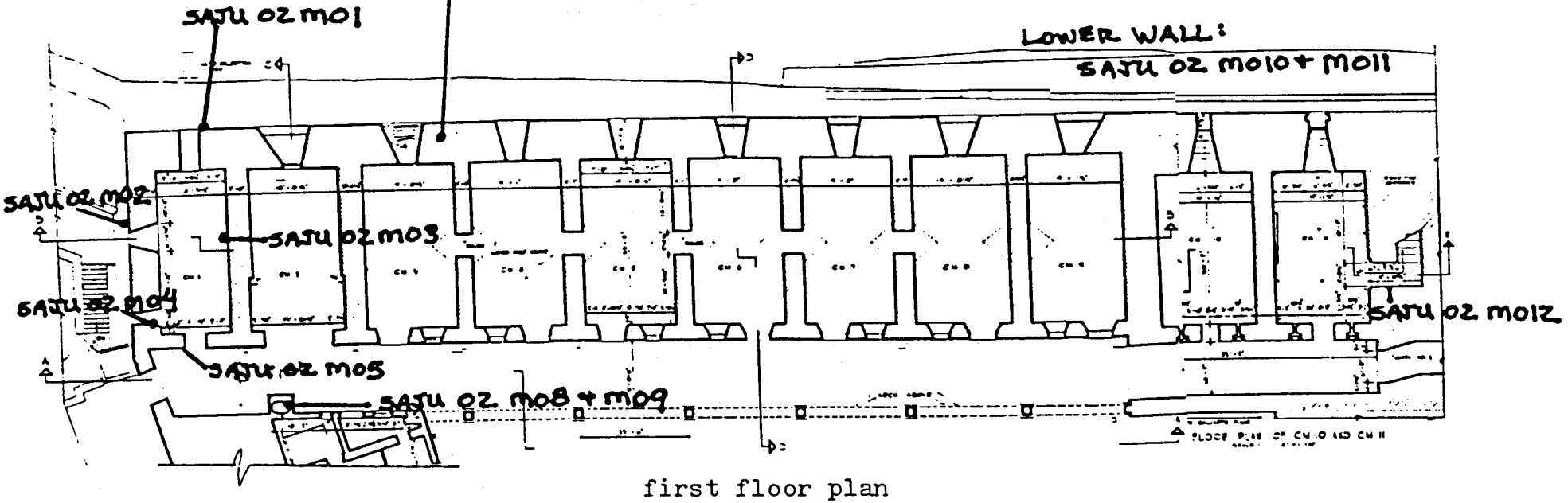
SAJU 02 M01	Stucco, exterior north facade as reached from north window of casemate (CM)-1
SAJU 02 M02	Stucco, exterior west facade as reached from west window (north side) of CM-1 (P01)
SAJU 02 M03	Plaster, east lower wall of CM-1 (P09)
SAJU 02 M04	Plaster, jamb of west window (southside) (P10)
SAJU 02 M05	Stucco, exterior doorway architrave of CM-1 (P02)
SAJU 02 M06	Stucco, on north parapet wall of upper terreplein
SAJU 02 M07	Stucco, above M06 (P15)
SAJU 02 M08	Mortar, between bricks of Guardhouse cupola
SAJU 02 M09	Mortar, ditto M08 but later mortar
SAJU 02 M10	Mortar, exterior lower north wall
SAJU 02 M11	Stucco, ditto M10 (P18)
SAJU 02 M12	Plaster, wall of east powder magazines stairway
SAJU 02 M13	Plaster, north wall of west powder magazine stairway to exterior terreplein

MORTAR SAMPLE LOCATIONS

Unit 02



second floor plan



first floor plan

Plan is by the Historic American Buildings Survey, 1963.

MORTAR ANALYSIS: SAJU 02

SAMPLE 02	m01	m02	m03	m04	m05	m06	m07	m08	m09
TYPE	Stucco	Stucco	Plaster	Plaster	Stucco	Stucco	Stucco	Mortar	Mortar
CLASS	B	B	B	B	B	C	B	C	C
PERIOD	II	II	Later Unknown	Later Unknown	VI (?)	II	II	IV	Later Unknown
% SAND	11	28	42	43	53	53	13	55	31
& FINES	5	7	9	5	0	10	6	7	12
% $CaOH_2$	83	65	50	53	47	38	80	37	57
SAND P/V	13	24	37	32	34	44	12	45	39
LIME P/V	94	73	56	59	51	42	91	42	64
CEMENT P/V									
FINES COLOR	10 YR 5/2	10YR 7/3	10 YR 8/1	2.5 Y 8/2	10 YR 6/4	7.5YR 5-6/6	10YR 8/2	7.5 YR 6/6	5YR 5-6/4
SHELL	YES						YES		

MORTAR ANALYSIS : SAJU 02 (cont'd)

SAMPLE 02	m10	m11	m12	m13					
TYPE	Mortar	Stucco	Plaster	Plaster					
CLASS	B	B	B	B					
PERIOD	Later Unknown	Later Unknown	II	III (?)					
% SAND	40	40	26	58					
& FINES	8	9	3	0					
% $CaOH_2$	53	52	70	42					
SAND P/V	31	32	19	38					
LIME P/V	59	58	79	46					
CEMENT P/V									
FINES COLOR	2.5 y 8/2	2.5 y 8/2	7.5 YR 5/4	10 YR 6/3					
SHELL			YES						

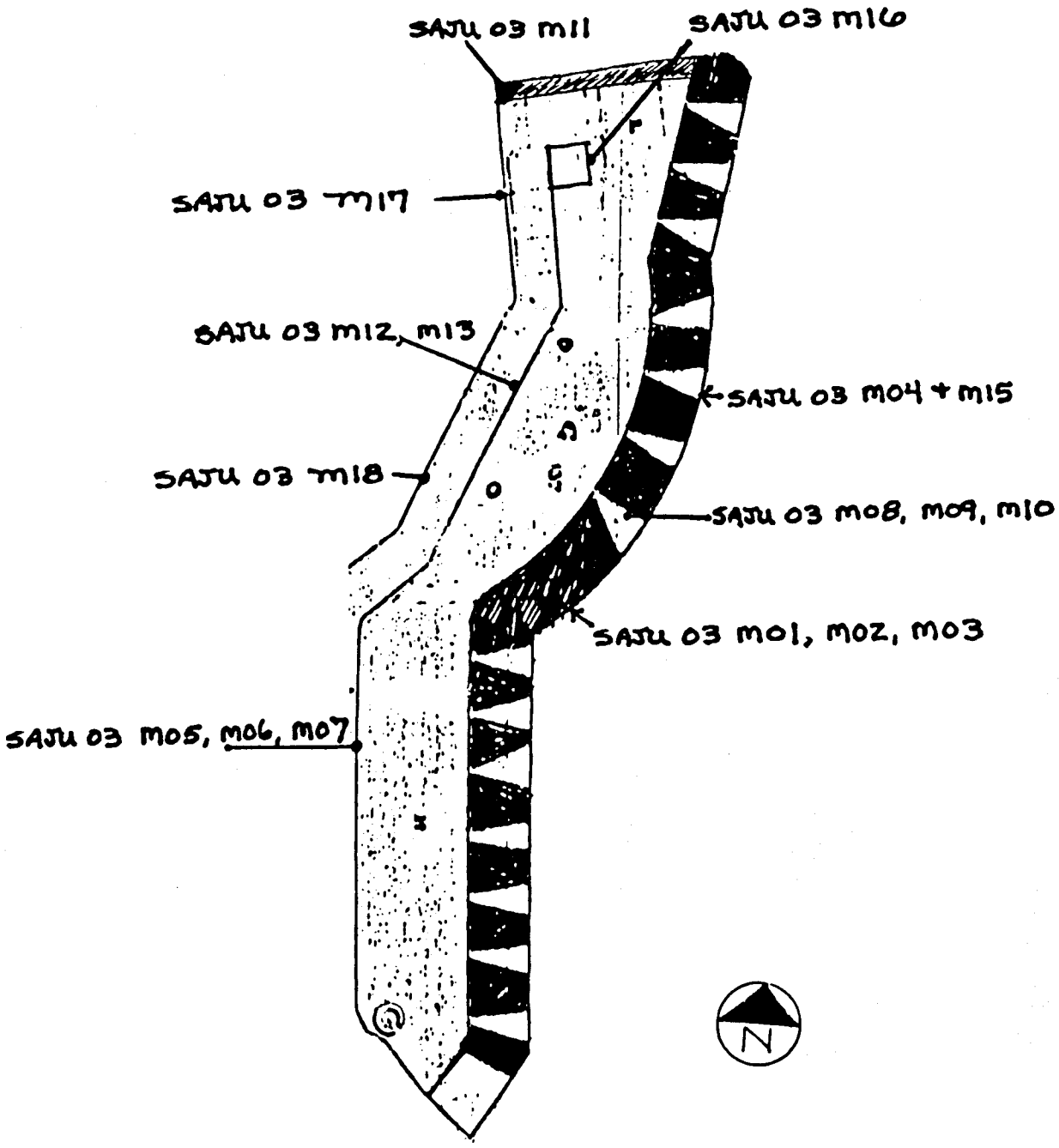
MORTAR SAMPLE LOCATIONS

Unit 03

SAJU 03 M01	Mortar or stucco, east curved wall as reached from bastion
SAJU 03 M02	Stucco applied on top of M01
SAJU 03 M03	Stucco applied on top of M02 (P01)
SAJU 03 M04	Mortar, brick arch (now enclosed) in east curved wall
SAJU 03 M05	Mortar, between bricks of west parapet wall above Troops' Quarters
SAJU 03 M06	Stucco, above M05
SAJU 03 M07	Stucco, above M06
SAJU 03 M08	Mortar, in rubble wall of east embrasure
SAJU 03 M09	Stucco, east embrasure
SAJU 03 M10	Stucco, ditto M09
SAJU 03 M11	Mortar, brick wall supporting signal pole (NW corner)
SAJU 03 M12	Mortar, ramp east wall
SAJU 03 M13	Stucco, above M12 (P02)
SAJU 03 M14	(No sample)
SAJU 03 M15	Morter, infilling former opening in east curved wall (below brick arch, M04)
SAJU 03 M16	Stucco, lower east wall of signal house P03)
SAJU 03 M17	Mortar, in rubble wall of ramp, north end exterior west wall (as reached from 02 terreplein)
SAJU 03 M018	Mortar, ramp coping wall beneath Portland cement (P04)

MORTAR SAMPLE LOCATIONS

Unit 03



Plan is a detail of the 1773 plan by O'Daly.

MORTAR ANALYSIS: SAJU 03

SAMPLE 03	m01	m02	m03	m04	m05	m06	m07	m08	m09
TYPE	Mortar or former stucco	Stucco	Stucco	Mortar	Mortar	Stucco	Stucco	Mortar	stucco
CLASS	A	C	B	C	C	B	C	B	C
PERIOD	I	II	Later Unknown	V (?)	II	II	II	II	II
% SAND	24	61	44	47	68	19	58	15	52
& FINES	16	17	7	13	18	9	17	3	12
% $CaOH_2$	60	22	49	40	14	72	25	82	35
SAND P/V	32	54	35	49	58	20	52	12	44
LIME P/V	67	25	55	45	16	81	28	93	40
CEMENT P/V									
FINES COLOR	[WHITE]	7.5YR 6-7/6	10YR 8/1	7.5YR 6/6	5YR 5-6/6	7.5YR 7/4	10YR 6-7/6	7.5YR 6/6	5YR 6/6
SHELL	YES								

MORTAR ANALYSIS : SAJU 03 (cont'd)

SAMPLE 03	m10	m11	m12	m13	m14	m15	m16	m17	m18
TYPE	Stucco	Mortar	Mortar	Stucco	–	Mortar	Stucco	Mortar	Mortar
CLASS	C	C	B	B		B	A	C	B
PERIOD	II	V	II	Later Unknown	No sample	VI	III	II	Later Unknown
% SAND	54	53	51	42		1	53	43	39
& FINES	21	14	4	4		11	0	16	9
% $CaOH_2$	25	33	45	54		89	47	42	53
SAND P/V	54	47	41	31		4	35	43	40
LIME P/V	28	36	50	61		100	52	47	60
CEMENT P/V									
FINES COLOR	7.5 YR 5-6/6	7.5YR 5-6/6	10YR 7/4	10 YR 5/2		10YR 7/3	10YR 6/4	5YR 6/6	10 YR 8/1
SHELL						YES			

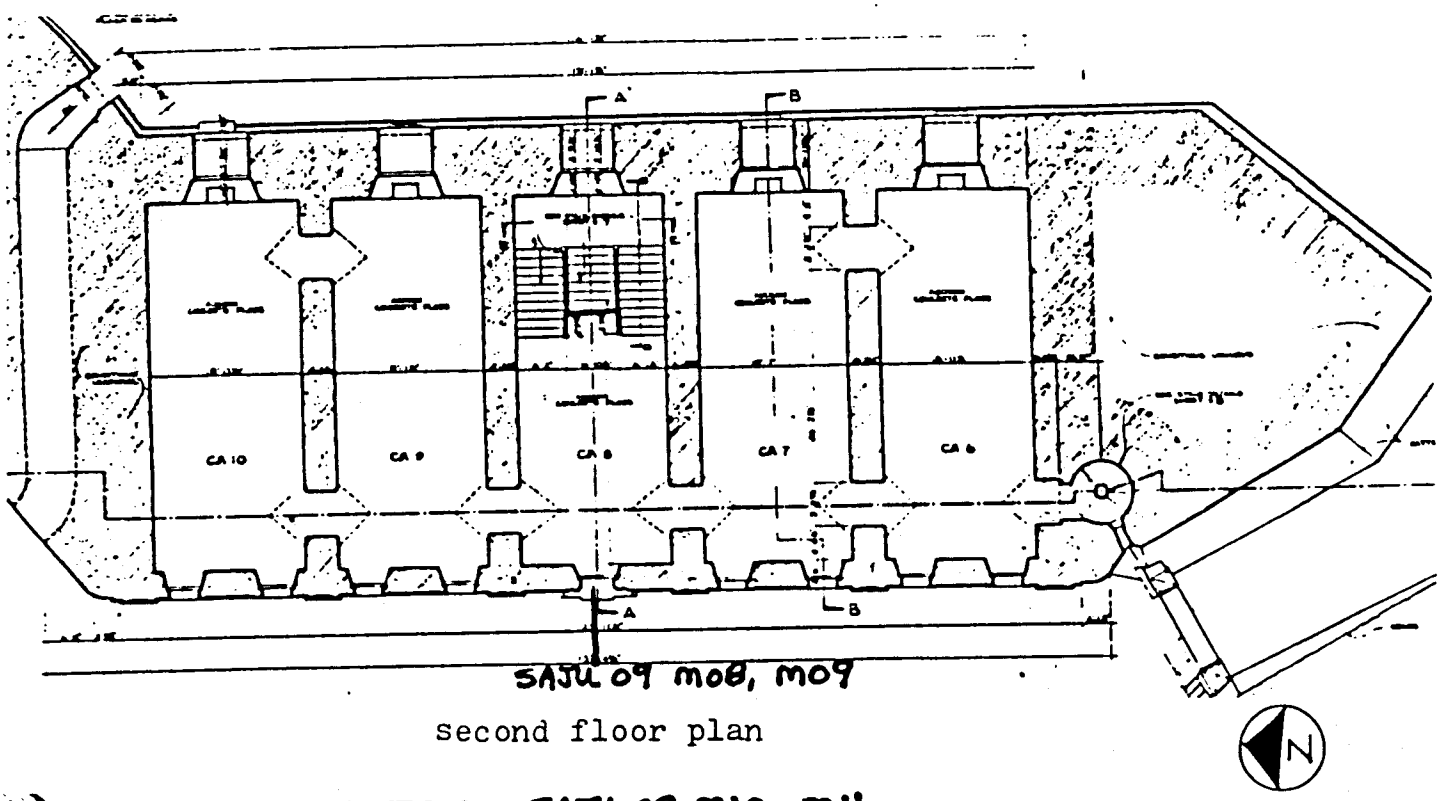
MORTAR SAMPLE LOCATIONS

Unit 09

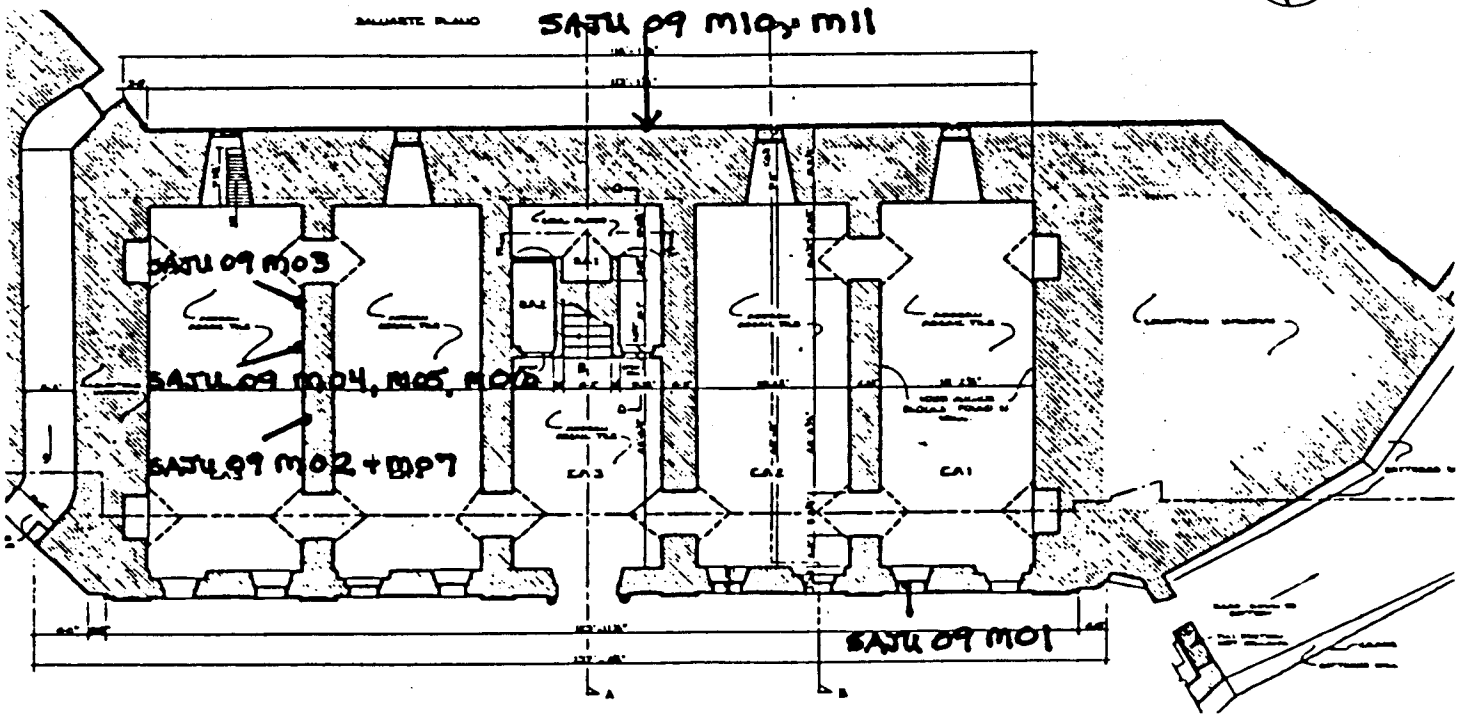
SAJU 09 M01	Mortar (?), window sill west facade first story
SAJU 09 M02	Mortar, patching former holes beneath plaster, interior walls of casemate (CM)-5
SAJU 09 M03	Mortar, interior rubble walls beneath plaster in CM-5
SAJU 09 M04	Plaster, upper interior walls (about 5 feet high) in CM-5 (P01)
SAJU 09 M05	Plaster, ditto M04 but about 2 feet high (P02)
SAJU 09 M06	Plaster, applied over M04 and M05 (later) (P03)
SAJU 09 M07	Ditto M02
SAJU 09 M08	Stucco, exterior window architrave, west facade hallway window (second story) (P04)
SAJU 09 M09	Mortar, infilling crack at window sill at second story hallway, west facade (P05)
SAJU 09 M10	Stucco, east exterior wall as reached from bastion
SAJU 09 M11	Stucco, applied on top of M10 (P06)

MORTAR SAMPLE LOCATIONS

Unit 09



second floor plan



first floor plan

Plan is by the Historic American Buildings Survey, 1962.

MORTAR ANALYSIS : SAJU 09

SAMPLE 09	m01	m02	m03	m04	m05	m06	m07	m08	m09
TYPE	Stucco	Mortar	Mortar	Plaster	Plaster	Plaster	Mortar	Stucco	Mortar(?)
CLASS	E	C	B	B	B	D	C	B	D
PERIOD	?	II	II	II	II	V-VI	II	VI	V-VI
% SAND	41	49	30	48	45	38	49	61	49
& FINES	0	12	2	2	3	7	15	9	8
% $CaOH_2$	58	39	68	50	52	-	36	30	44
SAND P/V	32	42	18	34	32	27	46	41	34
LIME P/V	64	43	76	56	59	26	40	7	16
CEMENT P/V						30 (Portland)		27 (Natural)	28 (Portland)
FINES COLOR	5YR 6/6	5YR 6/6	10YR 7/4-6	7.5YR 5/4	10YR 4/4	10YR 7/2	7.5YR 6/6	10YR 7/4-6	10YR 7/2-3
SHELL			Yes	YES	YES				

MORTAR ANALYSIS: SAJU 09 (cont'd)

SAMPLE 09	m10	m11
TYPE	Stucco	Stucco
CLASS.	C	A
PERIOD	II	VI
% SAND	70	34
& FINES	17	9
% $CaOH_2$	13	56
SAND P/V	59	24
LIME P/V	14	22
CEMENT P/V		35 (Portland)
FINES COLOR	7.5YR 6/6	10YR 8/1
SHELL		

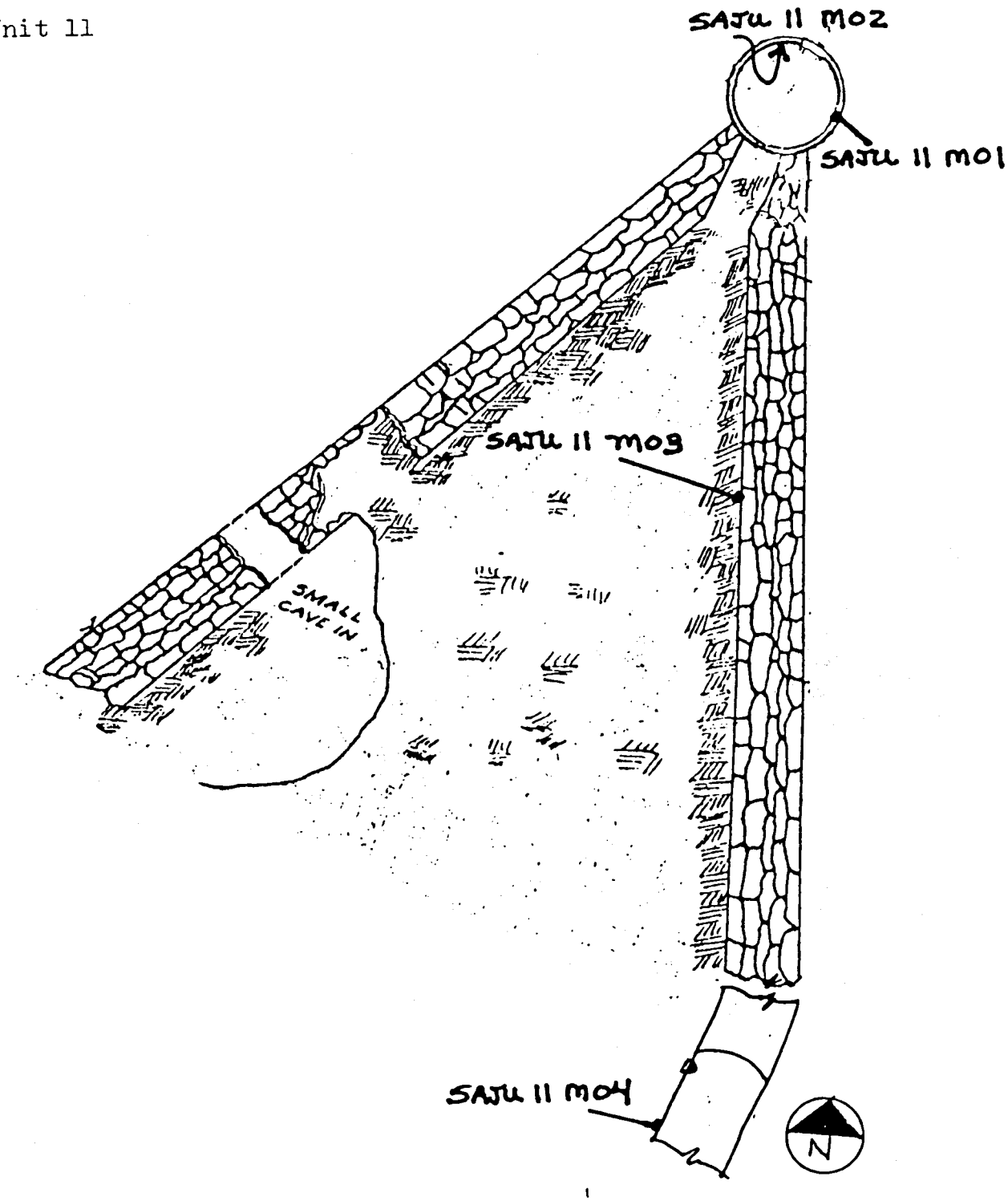
MORTAR SAMPLE LOCATIONS

Unit 11

SAJU 11 M01	Mortar, interior wall mortar at east window of sentry box
SAJU 11 M02	Plaster, interior sentry box (beneath later cement plaster) -- graffiti on walls dated 1938 & later
SAJU 11 M03a	Mortar, interior bedding in east rubble wall adjacent to sentry box
SAJU 11 M03b	Mortar, applied on top of M03a (now covered with Portland cement)-- original stucco?
SAJU 11 M04	Mortar, east rubble wall south of (up the slope from) the sentry box

MORTAR SAMPLE LOCATIONS

Unit 11



Plan is a detail from a drawing dated 1938-39 by the United States Department of the Army, Engineers Office.

MORTAR ANALYSIS: SAJU 11

SAMPLE 11	m01	m02	m03a	m03b	m04				
TYPE	Mortar	Plaster	Mortar	Mortar (former stucco?)	Mortar				
CLASS	B	B	C	A	C				
PERIOD	VI	VI	I	I	I				
% SAND	66	46	64	35	32				
& FINES	1	8	13	30	4				
% $CaOH_2$	33	46	24	35	64				
SAND P/V	44	35	52	55	24				
LIME P/V	36	52	27	39	72				
CEMENT P/V									
FINES COLOR	10 YR 6/4	10 YR 8/2	7.5 YR 6-7/6	[WHITE]	5 YR 5/6				
SHELL				YES					

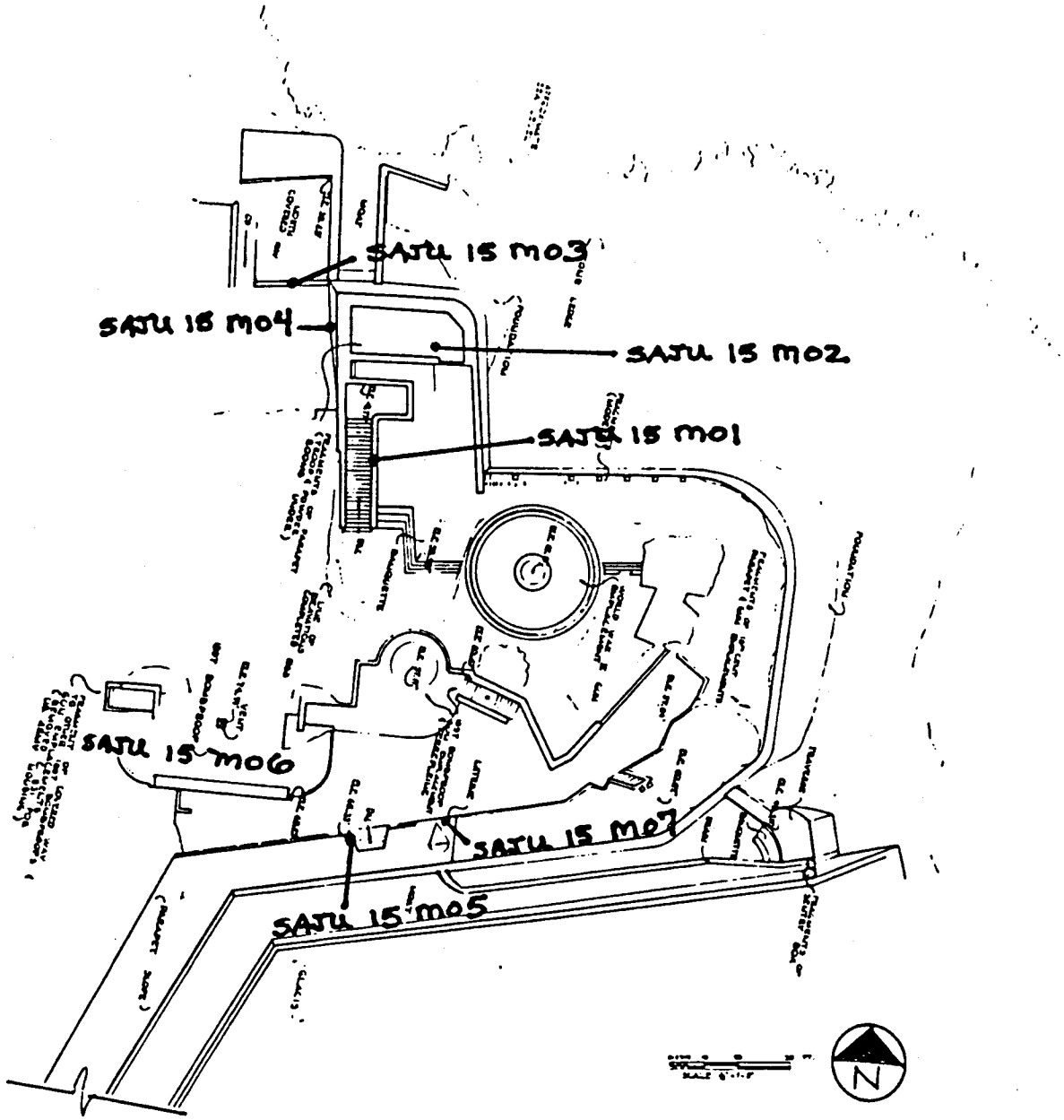
MORTAR SAMPLE LOCATIONS

Unit 15

SAJU 15 M01	Mortar, rubble wall, north stairway to 18th century troop and powder room vaults
SAJU 15 M02a	Mortar, interior rubble wall beneath plaster, southeast vault of troop & powder rooms
SAJU 15 M02b	Plaster, above M02a
SAJU 15 M03	Mortar, brick arch on south side of 18th century covered way (at north coast)
SAJU 15 M04	Mortar, cut stone at west doorway to 18th century troop and powder rooms
SAJU 15 M05	Stucco, south parapet wall at covered way -- graffiti dated 1914 and stucco appears to be a cement (P01)
SAJU 15 M06	Interior plaster, 1896 bombproof, southwest room (P02)
SAJU 15 M07	Mortar, rubble wall of south parapet adjacent to ca. 1896 latrine in 18th century embrasure

MORTAR SAMPLE LOCATIONS

Unit 15



Plan is by the Historic American Buildings Survey, 1963.

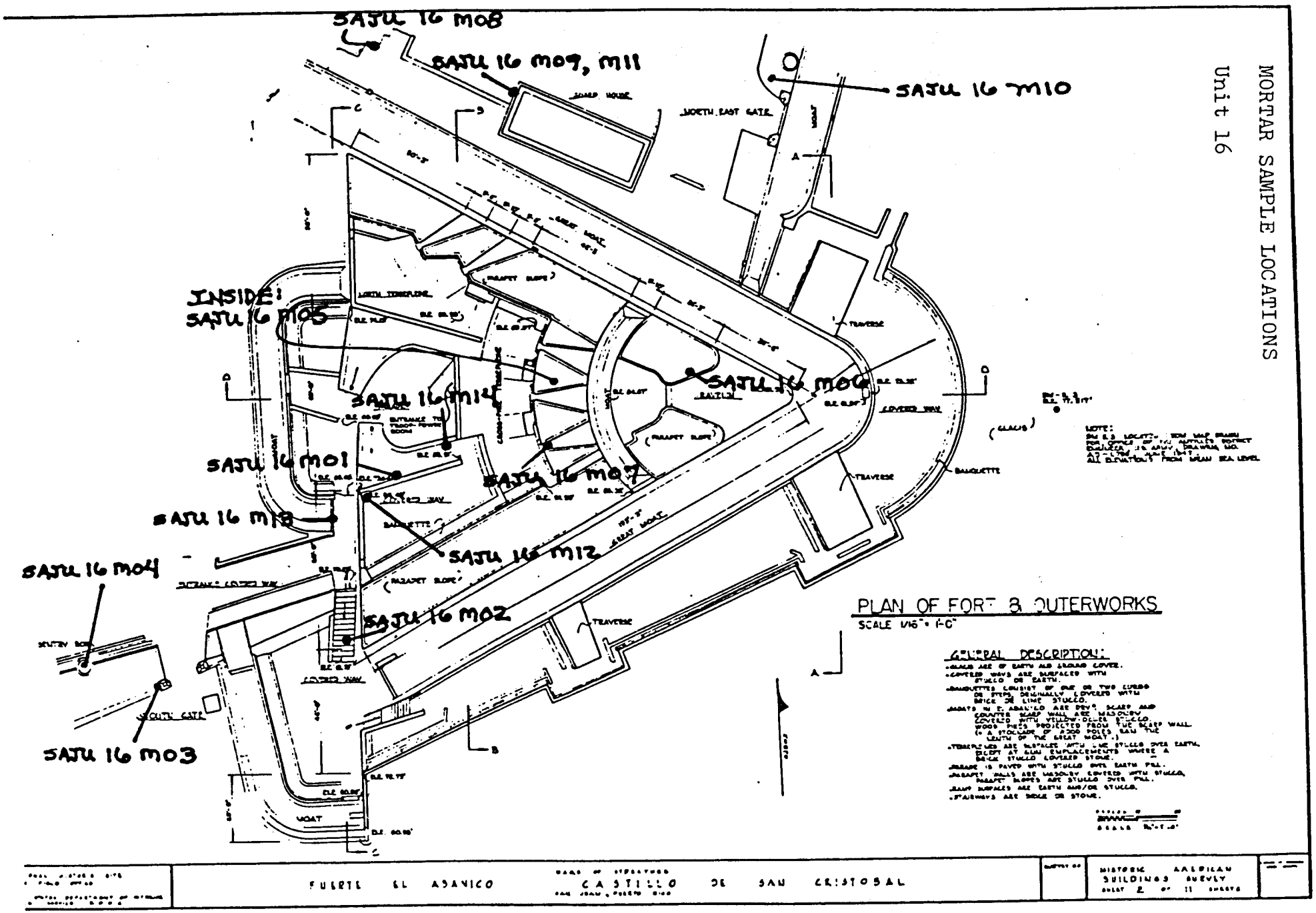
MORTAR ANALYSIS : SAJU 15

SAMPLE 15	m01	m02a	m02b	m03	m04	m05	m06	m07	
TYPE	Mortar	Mortar	Plaster	Mortar	Mortar	Stucco	Plaster	Mortar	
CLASS	C	C	B	C	A	B	B	C	
PERIOD	II	II	II	II	II	V	V	II	
% SAND	47	51	43	52	24	45	55	40	
& FINES	6	10	1	9	9	1	0	7	
% $CaOH_2$	47	39	56	40	67	54	44	54	
SAND P/V	35	44	27	41	22	29	34	33	
LIME P/V	53	44	62	45	75	44	48	60	
CEMENT P/V						12 (Natural)	?		
FINES COLOR	7.5 YR 6/6	7.5 YR 6/6	7.5 YR 6/6	5 YR 6/6-8	[WHITE]	10 YR 7/2-3	10 YR 6/4	5 YR 5/6	
SHELL									

MORTAR SAMPLE LOCATIONS

Unit 16

SAJU 16 M01	Stucco, south wall of gorge at ramp, graffiti dated 1848 and 1887 (P01)
SAJU 16 M02	Mortar, brick steps of southwest side of El Abanico
SAJU 16 M03	Mortar, South Gate west post (ca. late 1890's)
SAJU 16 M04	Plaster, South Gate sentry box interior (graffiti dated 1898 - 1904)
SAJU 16 M05	Plaster, El Abanico mining gallery beneath fan battery terreplein, east gallery (P02)
SAJU 16 M06	Mortar, filling voids in sandstone, fan battery parapet wall
SAJU 16 M07	Stucco, east parapet wall of fan battery (P03)
SAJU 16 M08	Mortar, deteriorated parapet wall on north side of main moat's covered way (west of Guardhouse)
SAJU 16 M09	Mortar, rubble wall of ca. 1890's Guardhouse, west facade (beneath stucco)
SAJU 16 M10	Mortar, top of wall adjacent to Northeast Gate
SAJU 16 M11	Stucco, Guardhouse exterior west wall
SAJU 16 M12	Mortar, El Abanico upper south terreplein, remains of former circular feature at northwest corner
SAJU 16 M13	Mortar, masonry bridge connecting the gorge of El Abanico with the original covered way
SAJU 16 M14	Paving, south ramp connecting the gorge with the upper terreplein of El Abanico



Plan is by the Historic American Buildings Survey, 1963.

MORTAR ANALYSIS : SAJU 16

SAMPLE 16	m01	m02	m03	m04	m05	m06	m07	m08	m09
TYPE	Stucco	Mortar	Mortar	Plaster	Plaster	Mortar	Stucco	Mortar	Mortar
CLASS	A	C	D	D	B	C	A	C	C
PERIOD	II	II	V	V	II	II	II	II	V
% SAND	27	56	50	48	43	49	28	35	56
& FINES	5	6	7	9	1	12	9	6	5
% $CaOH_2$	68	39	43	43	56	39	63	59	39
SAND P/V	22	41	33	37	29	43	26	29	41
LIME P/V	77	43	17	14	62	44	71	67	44
CEMENT P/V			26 (Portland)	30 (Portland)					
FINES COLOR	7.5 YR 8/2	5 YR 5/6	10 YR 8/2	10 YR 8/1	7.5 YR 5-6/2	5 YR 6-7/6	10 YR 8/1	5 YR 6/6	7.5 YR 7/6
SHELL	YES				YES				

MORTAR ANALYSIS : SAJU 16 (cont'd)

SAMPLE 16	m10	m11	m12	m13	m14				
TYPE	Mortar	Stucco	Mortar	Mortar	Stucco				
CLASS	C	B	C	C	C				
PERIOD	II	V	Later Unknown	Later Unknown	?				
% SAND	44	53	52	51	44				
& FINES	11	5	13	9	6				
% $CaOH_2$	44	42	35	39	50				
SAND P/V	38	39	50	37	34				
LIME P/V	50	57	39	11	23				
CEMENT P/V				32 (Natural)	30 (Natural)				
FINES COLOR	7.5YR 5-6/6	10YR 8/2	7.5YR 6/6	5YR 6/6	5YR 6/6				
SHELL									

APPENDIX I.

Paint Analysis, San Cristóbal

Paint Analysis, San Cristóbal

conducted by

Historic Preservation Center,
North Atlantic Regional Office,
National Park Service

1988

PAINT

Objective

The objective of paint analysis work at San Cristobal was to determine how the woodwork, exterior stucco, and interior plaster had been finished during the six major periods of construction. These periods were defined as follows:

I. 1625 - 1765

II. 1765 - 1809

III. 1809 - 1837

IV. 1837 - 1868

V. 1868 - 1898

VI. 1898 - 1987

Methodology

Small samples of paint were extracted at the site using an X-Acto knife fitted with a No. 18 blade. Sixty two (62) samples total were taken and placed in small individually labeled envelopes. These samples were then transported to the North Atlantic Historic Preservation Center in Boston where they were assigned log numbers and examined microscopically.

The log numbers are a three part code that describe the park, unit, and paint sample number. For example, at the Troops' Quarters, paint sample number one was assigned code "SAJU 09 P01." In this code, "SAJU" is San Juan National Historic Site, "09" unit 09, and P01" paint sample number one. In some cases,

paint samples were removed from stucco or plaster substrates that were also sampled for mortar analysis. These samples are cross referenced. Sample "SAJU 09 P01," for example, was removed from plaster substrate "SAJU 09 M04" -- or mortar sample number four.

After labeling, each paint sample was permanently mounted in a wax filled petri dish and examined in cross section with a binocular microscope at ten to seventy times magnification. The microscope used is a Bausch & Lomb "Stereozoom 7." Characteristics recorded include paint layer colors and numbers (chromochronologies) and paint types. Paints containing lead were identified by a spot chemical test using sodium sulfide. Paints composed of calcium carbonate ($CaC0_3$) were identified by a spot test using diluted hydrochloric acid. Selected samples were color matched to the Munsell Color Notation System.

Dating of specific paint layers was attempted based on known dates of construction, close study of the historical documentation, and information obtained from the mortar analysis.

Results and Conclusions

In general, most stucco and plaster surfaces were observed to have been finished with a paint composed of calcium carbonate, commonly known as whitewash. This "whitewash" was frequently pigmented. Exterior surfaces painted most frequently

were those that fronted the Plaza. The earliest exterior paint scheme, possibly dating to the early 19th century, was yellow and white as illustrated by the scale model of San Cristobal dated 1839 and the color washed drawings by Manuel Castro dated 1861. Until most recently, plastered interiors (not including the tunnels) appear to have been divided horizontally, with the lower walls painted a dark color and the upper walls a light color. Whether or not this was an original treatment or dates to a later time was difficult to pinpoint. Documentation suggests that paints used today are a vinyl-epoxy type.

The earliest woodwork finishes, removed from 18th century window shutters and window frames, were observed to be highly resinous and pigmented. Possibly these early paints contained a "liquid pitch and tallow" preservative described in 1808 as a finish (along with red ochre) for the palisades and gates of San Cristobal. Later layers appear to be oil-based paints, only a few of which contain lead.

For a more detailed discussion of paint evidence for each period, see chapter IV. A.

The pages that follow include a listing of paint samples for each unit, a written description of their locations, a graphic representation of their locations, and chromochronologies. A summary of representative paint samples is presented at the end of this Appendix.

PAINT SAMPLE LOCATIONS

Unit T-1

SAJU T-1 P01 Plaster wall, west end of T-1 south wall (M01)

Unit T-2

SAJU T-2 P01 Masonry wall, cut stone mortar joint at postern (M03)

SAJU T-2 P02 Wood door frame at west Plaza entrance

Unit T-3

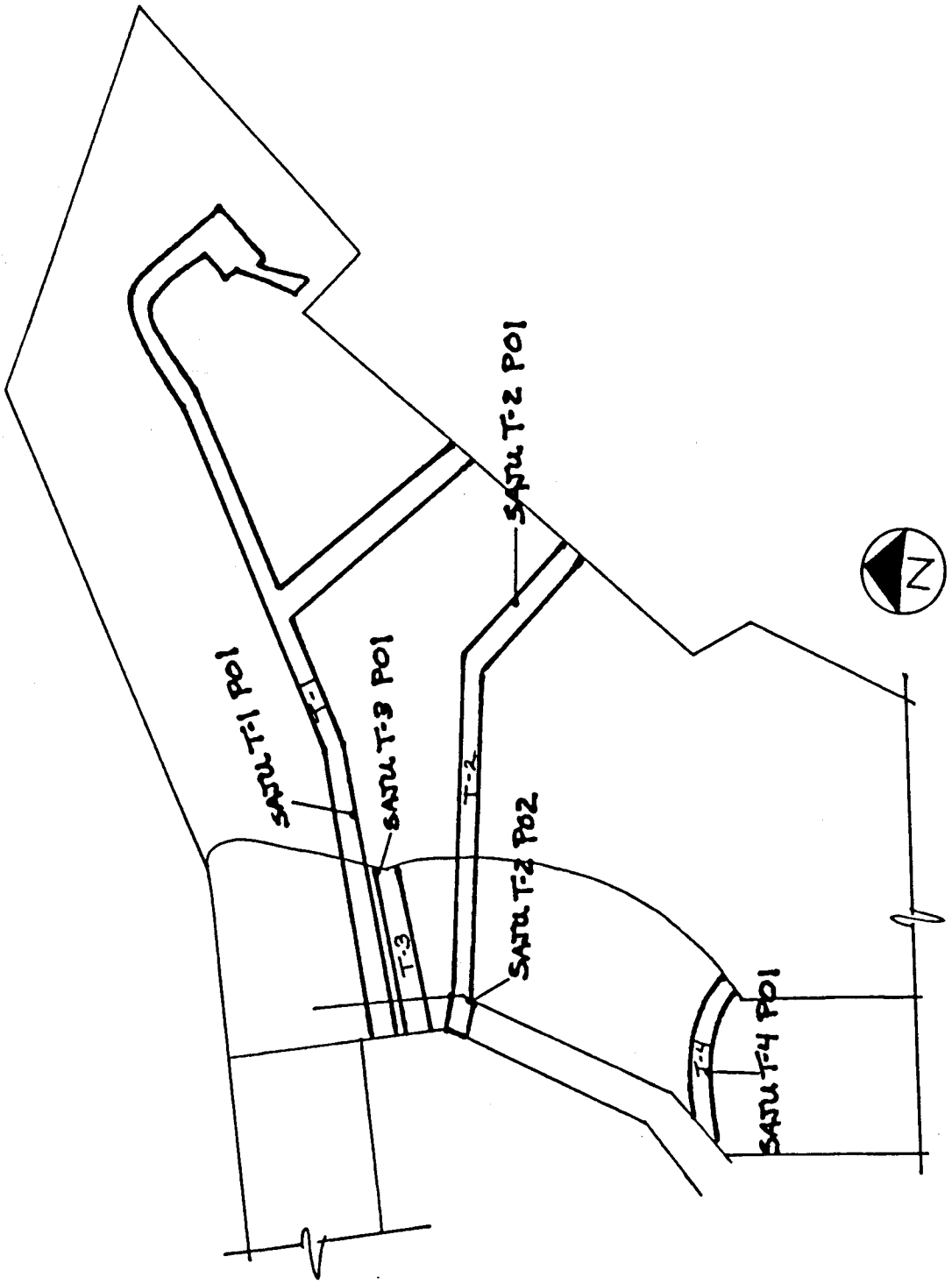
SAJU T-3 P01 Plaster wall, north side east end of T-3 (M02b)

Unit T-4

SAJU T-4 P01 Plaster wall, south side of T-4 (M02)

PAINT SAMPLE LOCATIONS

Units T-1, T-2, T-3, T-4



Plan by B. Yocum, 1987.

PAINT ANALYSIS: SAJU T-

Sample / Period	T-1 P01		T-2 P01	T-2 P02		T-3 P01		T-4 P01	
	(m01)-II		(m03)-II			(m2b)-after II		(m02)-II	
II			Black line						
						White		White	
	Red/orange (pigments)					Red		White	
V				White (x2)		Yellow		White	
				Black		Lt. Blue		White	
				Green		Yellow		mustard yellow	
				Green				Bright Yellow	
				Red					
				Pink-gray					
				Brick Red					
				Lt. Brown					

PAINT SAMPLE LOCATIONS

Unit 02

SAJU 02 P01	Exterior stucco wall, west facade second story (M02)
SAJU 02 P02	Exterior stucco, south doorway architrave of casemate (CM)-1 (M05)
SAJU 02 P03	Exterior stucco, north wall (upper) in hallway outside CM-1
SAJU 02 P04	Exterior stucco, south wall (lower) in hallway outside CM-1
SAJU 02 P05	Exterior stucco, south wall (upper) in hallway outside CM-1
SAJU 02 P06	Exterior stucco, window jamb in hallway outside CM-1
SAJU 02 P07	Exterior stucco, base of Guardhouse chimney (north side of Guardhouse)
SAJU 02 P08	Exterior stucco, south wall between CM-3 and CM-4
SAJU 02 P09	Interior plaster, CM-1, east lower wall (M03)
SAJU 02 P10	Interior plaster, west window jamb of CM-1 (M04)
SAJU 02 P11	Interior plaster, CM-1, west upper wall
SAJU 02 P12	Interior plaster, CM-2, lower east wall at north corner
SAJU 02 P13	Interior plaster, CM-3, west wall (about four feet high)
SAJU 02 P14	Exterior stucco, west ramp east wall
SAJU 02 P15	Exterior stucco, north parapet wall at terreplein, top surface (M07)
SAJU 02 P16	Exterior stucco, Guardhouse south wall north addition

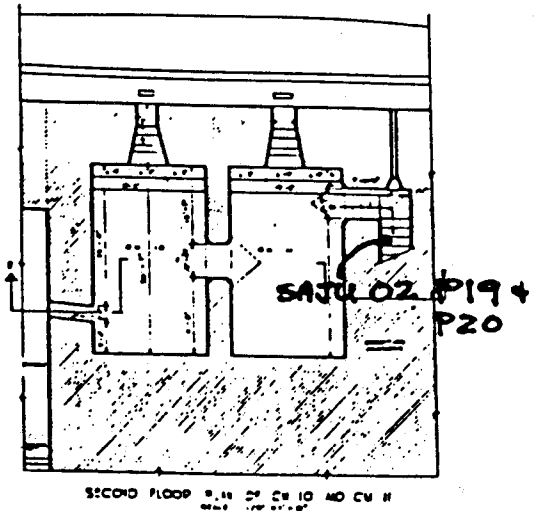
PAINT SAMPLE LOCATIONS

Unit 02 (cont'd)

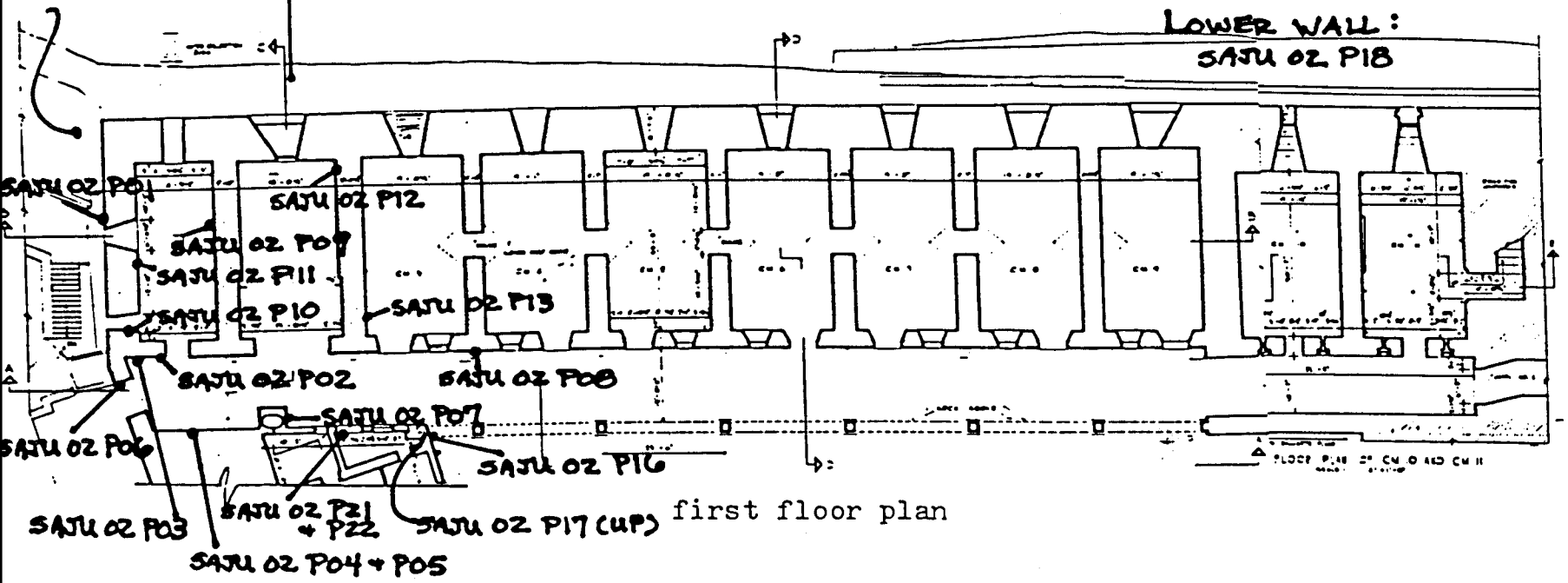
SAJU 02 P17	Exterior stucco, top southwest corner of gallery (as reached from Guardhouse roof)
SAJU 02 P18	Exterior stucco, lower north wall (M11)
SAJU 02 P19	Interior plaster, east stairhall of the two story powder magazines, west lower wall
SAJU 02 P20	Interior plaster, east stairhall of the two story powder magazines, upper wall
SAJU 02 P21	Wood window frame, middle window of Guardhouse north facade
SAJU 02 P22	Metal window bars, middle window of Guardhouse north facade

PAINT SAMPLE LOCATIONS

Unit 02



second floor plan



first floor plan

Plan by the Historic American Buildings Survey, 1963.

PAINT ANALYSIS: SAJU 02

Period / Sample	P01	P02	P03	P04	P05	P06	P07	P08	P09
	(m02) - II	(m05) - VI							(m03) - later
II				Gray					
				Gray-white					
				Gray					
				Gray-black					
				Gray-black					
				Black					
				Red					
				Red	Red				
				Gray-beige	Cream-white				
				Gray-beige	Cream-white				
IV				Gray-blue	Lt. yellow		Yellow	Yellow	
				Gray	White		Cream	White	
				Gray-white	White		White	Orange-pink	
				Brown-yellow	Lt. yellow		Dk. Gray	Red	
				Beige	Yellow	Yellow	White	White	
				Orange-red - GLAZE -	Cream	White	Yellow	Yellow	
VI	Cream			White	Cream	White	Yellow	[Portland cement]	[Portland cement]
	Brown	Cream	Lt. yellow	Brick red	White	White-cream	Yellow	White	Cream
	Brown	Cream	Lt. yellow	Brick red	Lt. yellow	White-cream	Yellow	Yellow	Brick Red
	Red-brown	Yellow	Mustard yellow	Blue-gray	Yellow	White-gray	Dk. green	-	Brick Red
	Black	Cream	White	Brick red	Red	-	Lt. gray		Gray
	White	Cream	Cream	Blue green	White	Cream	Blue-gray		Gray
	White	Cream	Cream	Gray (clear)	White	Cream	Lt. gray		Cream
	White	Cream	Cream-yellow	Gray	Cream-yellow	Gray			White
		White	White	Green	White				White
		White		Lt. Blue	White				Cream
				Green					

PAINT ANALYSIS: SAJU 02 (cont'd)

Period / Sample	P10	P11	P12	P13	P14	P15	P16	P17	P18
	(M04)-later					(M07)-II			(M11)-later
II			Red [remnants]						
			Black						
			Black						
			[cream white						
			[cream white						
			Black						
			Gray gray						
			Gray						
			Gray						
			White-gray						
IV	Yellow		Gray-blue				Yellow		
	White		Red				white Lt. Blue white		
	Orange-pink	Orange remnants	Gray				Orange-pink		
	Red		Brown-yellow	Cream			-		
	White	[Plaster]	-shear-	Cream		-	White		
	Yellow		Gray	White	Yellow		-		
VI	[Portland cement]		cream	White	-		[Portland cement]	[Portland cement]	
	White	White-cream	Brick red	White	White		White	Yellow	
	Yellow		Brick red	Red	Yellow	Yellow	Yellow	White	Yellow
	Cream		Brick red	Gray-white	orange-red			-	
			Brick red	Gray-white	Yellow				
			White	Black					
		White-cream		Gray					
		White-cream		Pink-gray					
		White-cream		Gray					
		White-cream		Gray					
				Cream					

PAINT ANALYSIS: SAJU 02

Period	Sample P19		P20	P21	P22					
	lower wall	mid wall		(reused wood?)						
II										
III				White-brown / Gray-blue						
				Green						
				White (x2)						
				Black						
				Green						
				White / Green						
				Pink						
IV	Brown	White	Cream-white	Green						
	Brown	White	Cream-white	Red						
	Brown	White	Cream-white	Red						
	Brown	Brown	Cream-white	Red						
	Brown	Gray	Cream-white	Red						
	Brown	Green	Cream-white	Green						
VI	Brown	Red	Cream-white	Lt. gray / Red						
	Brown	White	Cream-white	Green (moss)	Lt. Gray-WH					
	Brown	Red	Cream-white	mustard yellow	Red					
	Brown	White	Cream-white	Black	Black					
	Black	Red	Cream-white	Black	Red					
				Black	Black					
				Red	Red					
				Black	Black					
				Black	Black					
				Black	Black					
				Black	Black					

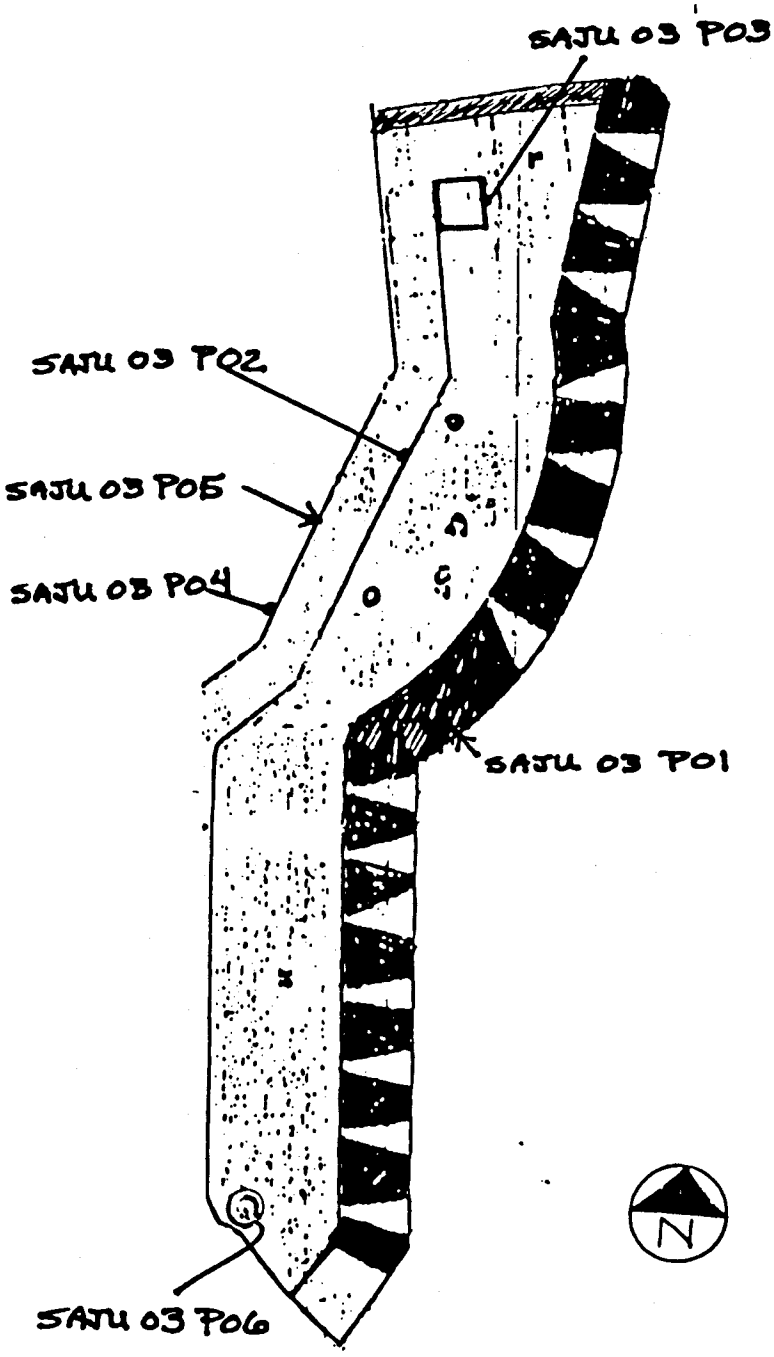
PAINT SAMPLE LOCATIONS

Unit 03

SAJU 03 P01	Exterior stucco, east curved wall as reached from bastion (M03)
SAJU 03 P02	Exterior stucco, ramp east wall (M13)
SAJU 03 P03	Exterior stucco, lower east wall of signal house (M16)
SAJU 03 P04	Exterior stucco, ramp coping wall beneath later Portland cement (M18)
SAJU 03 P05	Exterior stucco, ramp west wall as reached from Plaza
SAJU 03 P06	Exterior stonework mortar, stair tower doorway

PAINT SAMPLE LOCATIONS

Unit 03



Plan is a detail of the 1773 plan by O'Daly.

PAINT ANALYSIS: Unit 03

Period	Sample P01	P02	P03	P04	P05	P06			
	(m03) Later Unknown	(m13) Later	(m16) III	(m18) Later					
II						Red + Black Lines			
IV					White				
					white - shear -				
		White	White		White				
		Lt. blue	Gray-white		Lt. blue				
		White	-		-				
		Pink-orange	Pink-beige		Pink-orange				
	yellow	-	White	yellow	-				
VI		[Portland cement]	[Portland cement]	[Portland cement]	[Portland cement]				
			White (x2)		-				
			Yellow (x2)		yellow				

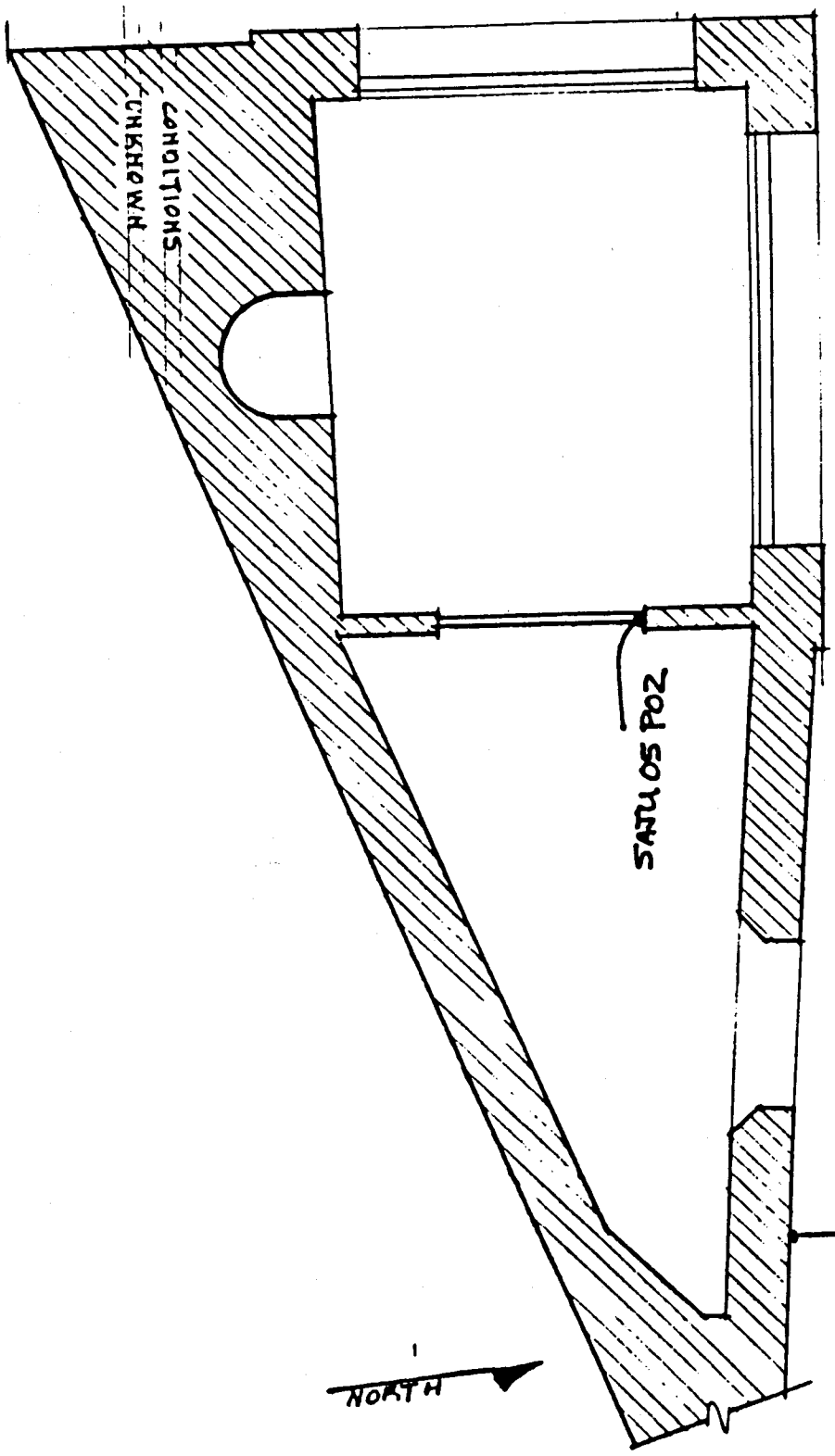
PAINT SAMPLE LOCATIONS

Unit 05

SAJU 05 P01	Exterior stucco, north wall to east of doorways
SAJU 05 P02	Interior stucco, interior doorway jamb

PAINT SAMPLE LOCATIONS

Unit 05



Plan by Richard Crisson, 1987.

PAINT ANALYSIS: SAJU 05

Period	Sample P01	P02							
VI	[Portland Cement]	[Portland Cement]							
	Yellow	Yellow							
	[White Yellow	[White Yellow							
		White							
		White							
		White							
		White							
		White							

PAINT SAMPLE LOCATIONS

Unit 09

SAJU 09 P01	Plaster, interior south wall (upper) of casemate (CM)-5 (M04)
SAJU 09 P02	Plaster, interior south wall (lower) of casemate (CM)-5 (M05)
SAJU 09 P03	Plaster, second plaster finish on interior walls of CM-5 (M06)
SAJU 09 P04	Exterior stucco, second story window architrave, west facade (M08)
SAJU 09 P05	Mortar, infilling crack in second story window sill, wood (M09)
SAJU 09 P06	Exterior stucco, east wall as reached from bastion (M011)
SAJU 09 P07	Exterior stucco, west facade, first story
SAJU 09 P08	Exterior stucco, west facade window jamb, first story
SAJU 09 P09	Exterior stucco, west facade, red mortar (patch?)
SAJU 09 P10	(omitted)
SAJU 09 P11	Interior wood stair balusters, second story hall
SAJU 09 P12	Exterior wood door, exterior side, main center entrance to Troop's Quarters
SAJU 09 P13	Wood shutter, west facade, window 205, interior side
SAJU 09 P14	Wood shutter, west facade, window 205, exterior side
SAJU 09 P15	Wood shutter, west facade, window 206, interior side
SAJU 09 P16	Wood shutter, west facade, window 206, exterior side

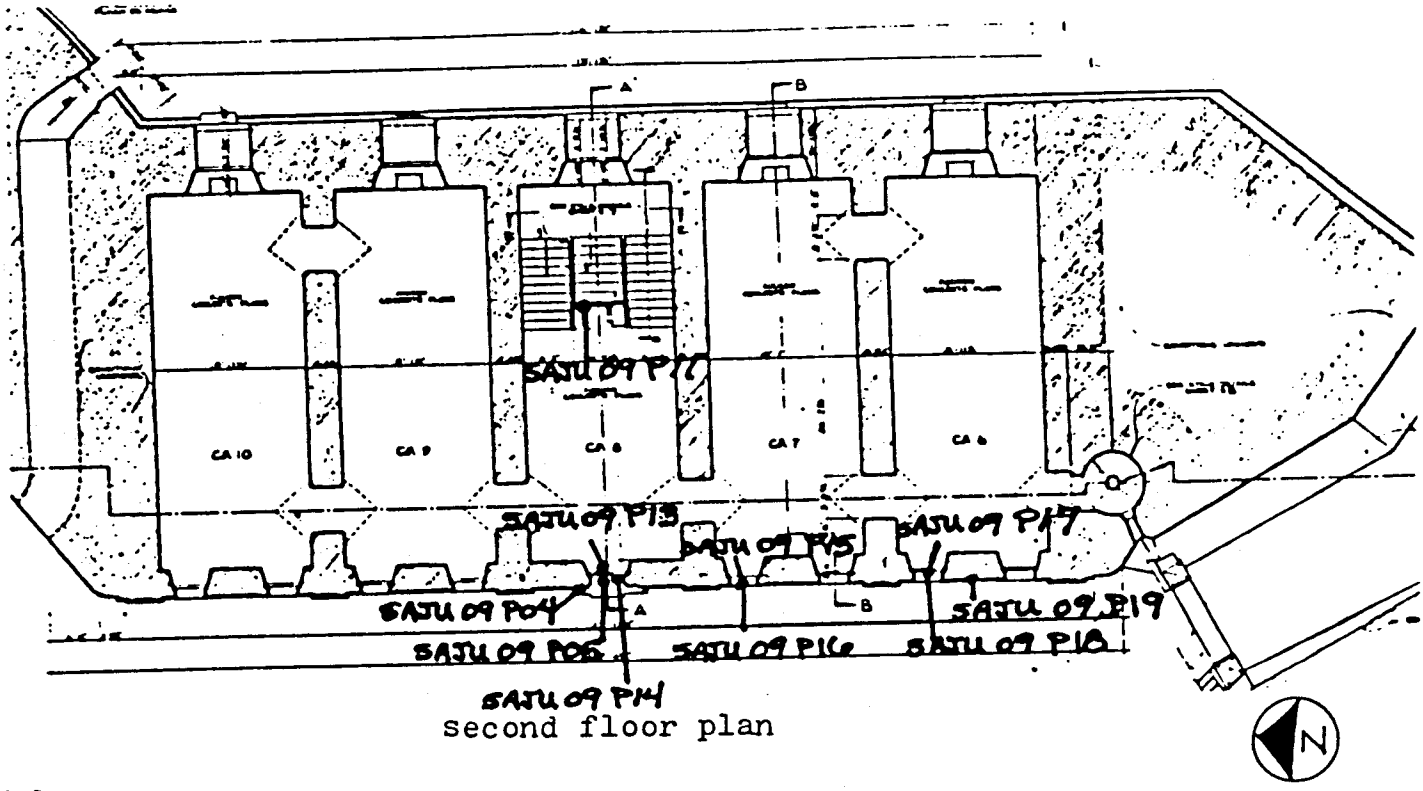
PAINT SAMPLE LOCATIONS

Unit 09

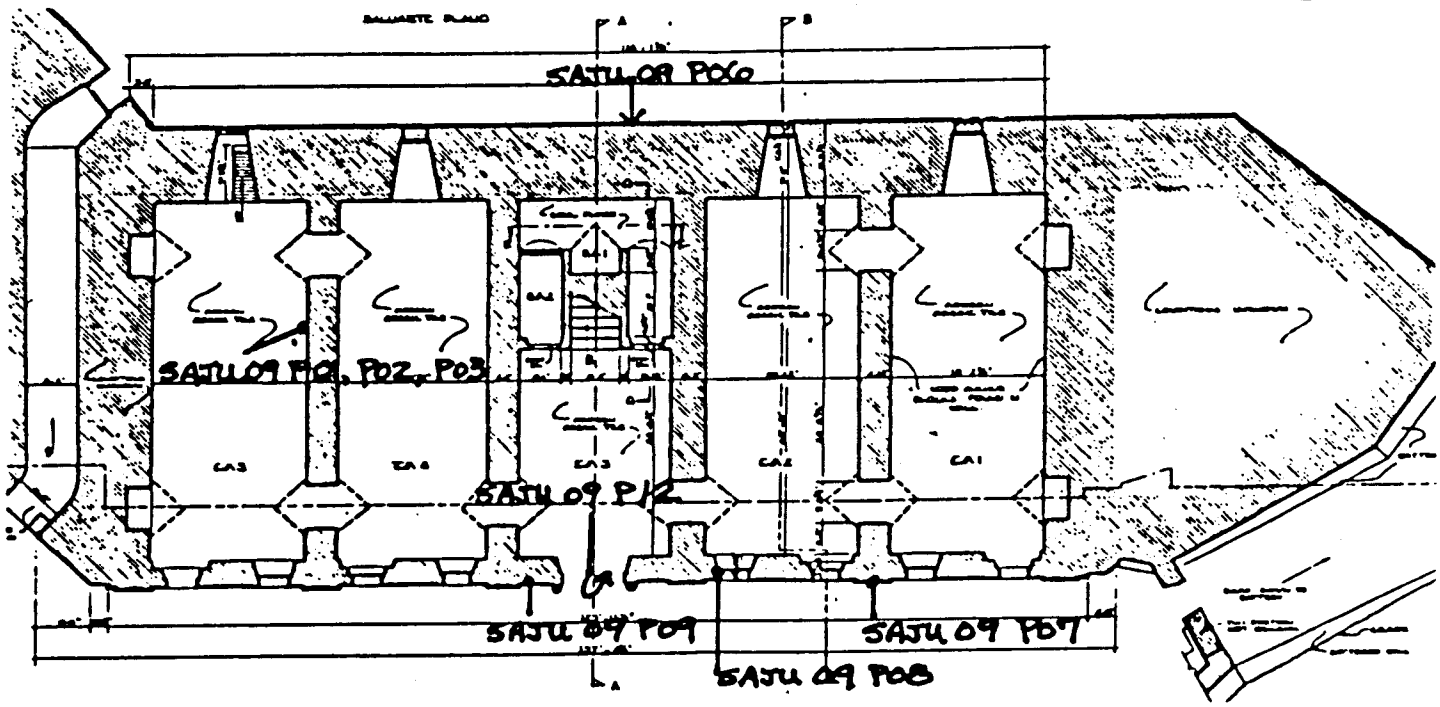
SAJU 09 P17	Wood shutter, west facade, window 208, interior side
SAJU 09 P18	Wood shutter, west facade, window 208, exterior side
SAJU 09 P19	Exterior stucco, west facade at second story
SAJU 09 P20	Window frame in storage in park's artifact collection, North Casemates. Possibly from the Troops' Quarters, removed during restoration work in the 1970's.

PAINT SAMPLE LOCATIONS

Unit 09



second floor plan



first floor plan

Plans by the Historic American Buildings Survey, 1962.

PAINT ANALYSIS: SAJU 09 (cont'd)

Period	Sample P10	P11	P12	P13	P14	P15	P16	P17	P18
II					Yellow				
					Gray-blue				
					[White Lt. green				
				Black	Gray	Black			
				Red	Black	Red (lead)		Red	
				Gray	Brown	Gray (lead)		Dk green	
				Red	Black	Red		Black	
				Green	Dk. green	Green		Dk. green	
				Gray-black	Beige-brown	Black-brown	Brown-yellow	Brown	
				White	White	-Green- White (lead)	White	White (x2)	
				Blue-gray	Blue-gray	Blue-gray	Blue-gray	Blue-gray	
				White	White	White	White	White	
				White	White	White	White	White	
			Green	Gray	Gray	White	Gray	Gray	Lt. Gray
VI			Red	Red	Red	Red (x2)	Red	Red	Red
			-	-	Green	Gray	Green	-	-
			Black	Black	Black	Black	Black	Black	Black
			Green	Green	Green	Green	Green	Green	Green
		- orange glaze -	mustard yellow	mustard yellow	mustard yellow	Yellow	mustard yellow	mustard yellow	mustard yellow
		Orange-brown	Brick red	Brick red	Orange-red	Orange-red	Red	Orange-red	
		Red brown	Brown	Brown	Brown-red	Brick red		Brick red	
		Lt. green	Brown -	Brown Lt. Green	Brown Lt. Green	Lt. Green		Lt. Green	
		Green	Green	Green	Green	Green		Green	
		Green	Green	Green					
		Green	Green	Green					
		Green	Green	Green					

PAINT ANALYSIS: SAJU 09

Period	Sample P19	Sample P20							
II		Red							
		Cream-yellow							
		[Lt. Gray Lt. Blue-green							
		[gray Black							
		[Brown-yellow Red							
		Green							
		Red-brown							
		Green							
		White							
		White							
		Blue-gray							
		Green Gray-green							
	Pink	White White							
	- -	White White							
VI	[Portland cement]	Red (x2)							
	White	Green (x2)							
	Yellow	Black							
		Green							
		Mustard Yellow							
		Orange-red							
		Brown-red							
		Lt. Green							
		Dk. Green							
		Dk. Green							

United States Department of the Interior
NATIONAL PARK SERVICE
Virgin Islands National Park
Box 806 - St. Thomas, V. I. 00801

IN REPLY REFER TO:
H30

May 8, 1974

Memorandum

To: Superintendent Lloyd K. Whitt, San Juan NHS

From: Architect, Virgin Islands NP

Subject: Paint analysis of woodwork, Troop Quarters, San Juan National Historic Site

The microinspection of the paint from a shutter of the Troop Quarters made at Harpers Ferry by Mr. Walter Nitkiewitz is very helpful and informative. If it is supplemented with some additional inspection it will provide us with good comparative data on the original finishes of various periods.

I suggest that Harpers Ferry be requested to make microinspections of the finishes of both the front and back of door A with a separate inspection of finishes of the pine boards that were used to repair the lower section of the door. It would also be helpful to get front and back inspections of Doors B and E, Shutters 105 and 209, a total of 12 micro-inspections.

All of the above listed sash is scheduled to be repaired through Harpers Ferry and the paint samples could be taken there directly from the sash.

As we have discussed the shutters 209 and Door B are slightly different in character from the other sash of the ground floor and is possibly an early replacement of the original sash. The pineboard replacements on doors A post-dates the Spanish American War and microinspections of this material will provide us with a good comparative data.

Although the data gathered from these inspections may not provide us with any definite proof of relative age of the woodwork it will hopefully

NPS/SERO/SCRPC files
SAJU = San Cristobal Troop Qts.

provide sufficient information for sound conjectures and maybe confirm questions posed by differences in construction and other factors.

Enclosed with this are copies of the material forwarded to Vernon Ingram and a copy of my memorandum.

Frederik C. Gjessing

Enclosures

isted . st to most recent: 1974 (cont'd)

1. Slate grey *
2. White
3. Red
4. Pale green
5. Light brown
6. White
7. Dark grey
8. Off white or light grey
9. Bright green
10. Black
11. Light grey
12. Thick white
13. Deep brick red
14. Light brick red
15. Warm off white
16. Cool off white
17. Grey
18. Light green
19. Thin white
20. Thin green
21. White
22. Light green

Walter Nitkiewicz
microinspection
of paint on shutter
Troop quarters.

*Remnants of paint under #1 are white. This appears to be the primer which was applied on the textured and absorbent wood and is therefore bonded to it.

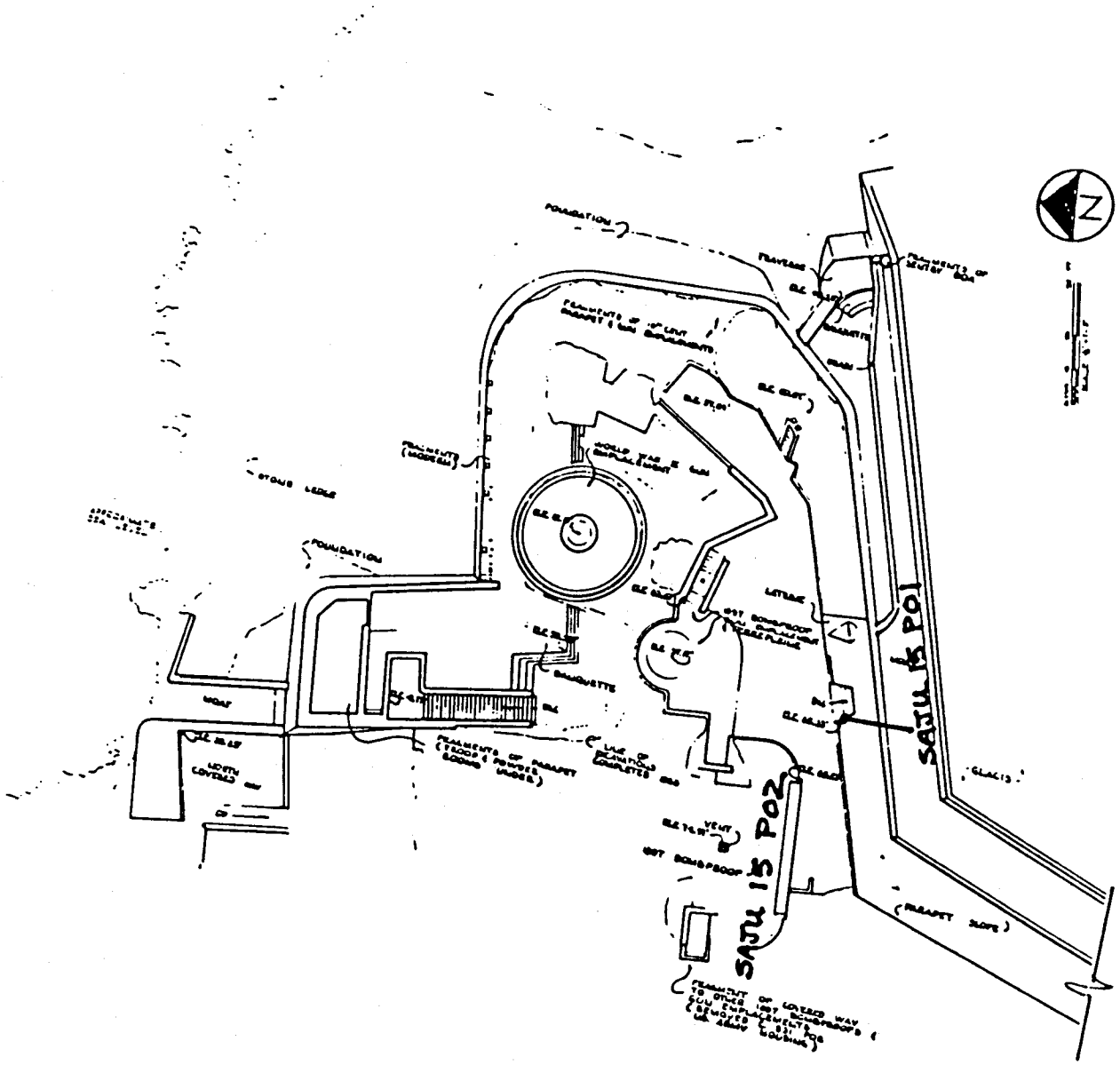
PAINT SAMPLE LOCATIONS

Unit 15

SAJU 15 P01	Exterior stucco at south parapet wall -- graffiti dated 1914 (M05)
SAJU 15 P02	Interior plaster, 1896 bombproof, southwest room (M06)

PAINT SAMPLE LOCATIONS

Unit 15



Plan by the Historic American Buildings Survey, 1963.

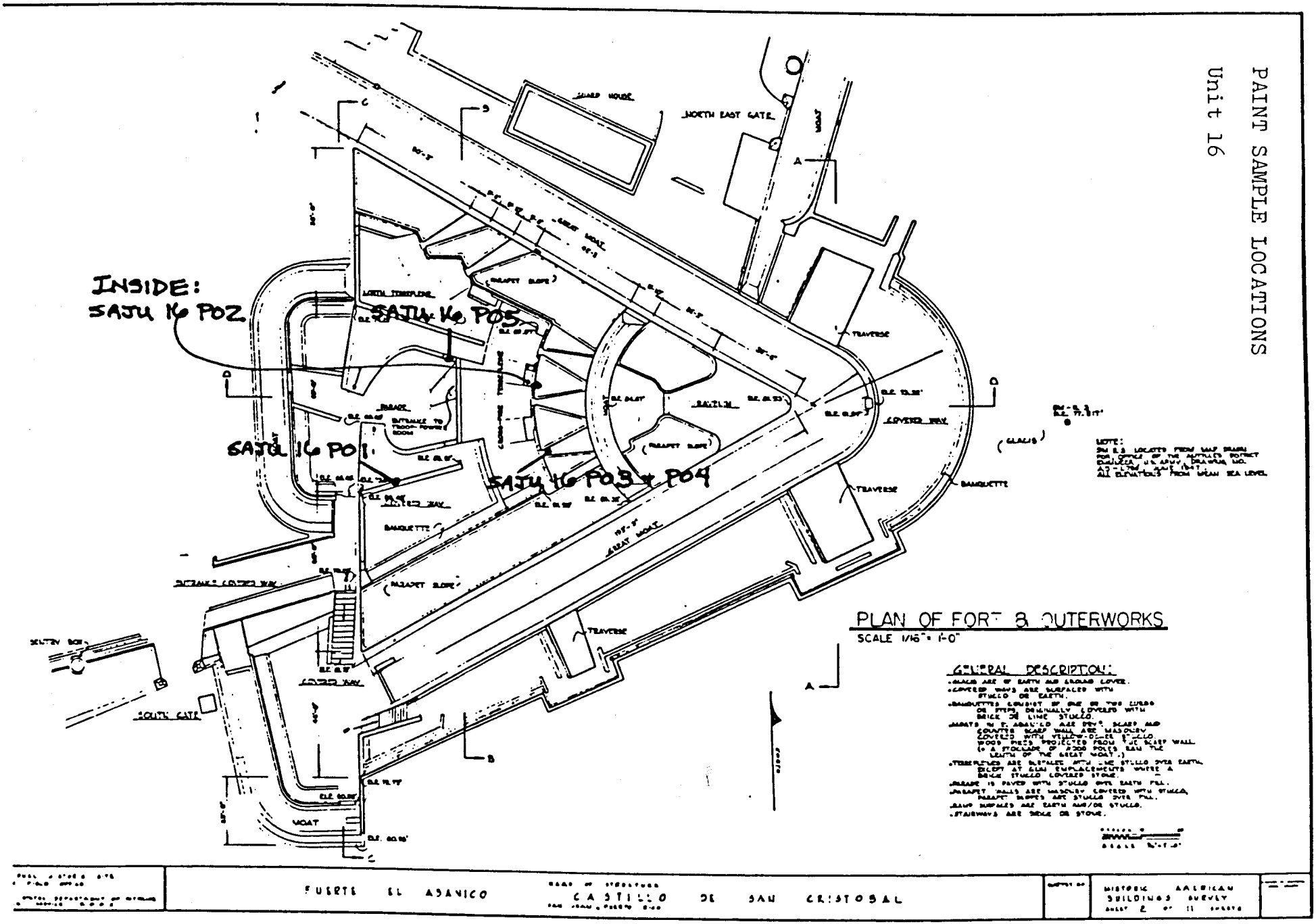
PAINT ANALYSIS: Unit 15

Period	Sample P01	P02							
	(mo5) - I	(mo6) - I							
V	white								
	white								
VI	Pink/yellow	yellow							
	Gray								

PAINT SAMPLE LOCATIONS

Unit 16

SAJU 16 P01	Exterior stucco, south wall of gorge at ramp, graffiti dated 1848 and 1887 (M01)
SAJU 16 P02	Interior plaster, El Abanico east mining gallery beneath fan battery terreplein (M05)
SAJU 16 P03	Exterior stucco, east parapet wall of fan battery (M07)
SAJU 16 P04	Exterior stucco, corner quoin at embrasure of east parapet wall of fan battery
SAJU 16 P05	Exterior stucco, decorative scrollwork at top of west ramp from the gorge to the upper terreplein



Plan by the Historic American Buildings Survey, 1963.

PAINT ANALYSIS: SAJU 16

Period	Sample P01	P02	P03		P04	P05				
	(m01)-II	(m05)-II	(m07)-II							
			a	b						
II		White								
		White								
		White								
		White				Yellow-beige				
		Black (Horizontal Line)				-dirt- White				
	White Yellow			Gray		Yellow				
				Gray		Gray-black				
VI			Red	Black	Black	Green				

REPRESENTATIVE PAINT SAMPLES (Wood)

	Window Frame (exterior side)	Exterior Window Shutter	Interior Window Shutter
	09 P20	09 P14	09 P13
Period			
II	Red		
	Cream-yellow	yellow	
	Light Gray	Gray-Blue	
	Light Blue-Green	[WHITE Light Green	
	Gray	Gray	
	Black	Black	Black
	Brown-yellow	Brown	-
	Red	-	Red
	Green	Black	Gray
	Red-Brown	-	Red
IV	Green	Dark Green	Green
	White	Beige-Brown	Gray-Black
	White	White	White
	Blue-Gray	Blue-Gray	Blue-Gray
	Green	-	-
	Gray-Green	-	-
	White	-	-
	White	White	White
	White	White	White
	White	Gray	Gray
VI	Red	Red	Red
	Red	Red	-
	Green	Green	-
	Black	Black	Black
	Green	Green	Green
	Mustard Yellow	Mustard Yellow	Mustard Yellow
	Orange-red	Brick red	Brick red
	Brown-red	Brown	Brown Brown
	Light Green	Light Green	Light Green
	Green	Green	Green
	Green	-	Green
	Green Green	-	Green Green

REPRESENTATIVE PAINT SAMPLES (Stucco)

	Guardhouse South Wall	Troops' Quart. Ext. Window Jamb	El Caballero Ramp Plaza Wall
	02 P16	09 P08	03 P05
Period			
II			
IV	Yellow	Gray-White	White White
	White	White	White
	Light Blue	White	Light Blue
	White	White	-
	Orange-Pink	Blue	Orange-Pink
	White	White	
VI	[Portland Cement]	[Patching]	[Portland Cement]
	White	White	-
	Yellow	Yellow	Yellow

REPRESENTATIVE PAINT SAMPLES (Plaster)

North Casemates			
	CM-1 upper wall	CM-1 lower wall	CM-2 lower wall
	02 P11	02 P09	02 P12
Period			
II			Red
			Black
			Black
			[Cream white
			[Cream white
			Black
			Gray
			Gray
			Gray
			Gray
			White-gray
			Gray-blue
	Orange (remnants)		Red
			Gray
	[Plaster]		Brown-yellow - shear
VI		[Portland Cement]	Gray
	White-cream	Cream	Cream
	-	Brick red	Brick red
	-	Brick red	Brick red
	-	Gray	Brick red
	-	Gray	Brick red
	White-cream	Cream	White
	White-cream	White	
	White-cream	White	
	White-cream	Cream	

REPRESENTATIVE PAINT SAMPLES (Plaster)

North Casemates East Stairway				
	Upper wall	Mid wall	Lower wall	
	02 P20	02 P19	02 P19	
Period				
IV. (II ?)	Cream-white	White	Brown	
	Cream-white	White	Brown	
	Cream-white	White	Brown	
	Cream-white	Brown	Brown	
	Cream-white	Gray	Brown	
	Cream-white	Green	Brown	
	Cream-white	Red	Brown	
	Cream-white	White	Brown	
	Cream-white	Red	Brown	
	Cream-white	White	Brown	
	Cream-white	Red	Black	

REPRESENTATIVE PAINT SAMPLES (Plaster)

Troops' Quarters			
	CM-5, upper wall	CM-5, lower wall	CM-5, later plaster
	09 P01	09 P02	09 P03
Period			
II		Brown	
		Brown	
		Brown	
		Black	
		Black	
		Black	
		Black	
		Black	
		Brown	
		Mustard yellow	
		Green	
		Red	
		Green	
		Cream	
		Gray	
	Cream	Mustard yellow	
	Cream	Cream	
	Cream	Gray	
	Cream	Cream	
	White	Red	
VI	[Portland cement]	[Portland cement]	[Portland cement]
			White - cream
			Green
			Gray
			Red
			White

APPENDIX J.

Explanation of Spanish Measurements
and their Historic Definitions

Explanation of Spanish Measurements and their Historic Definitions

compiled by

E. Blaine Cliver

(from sources cited in full in the Bibliography)

1949

[The World Almanac, (NY: New York World, Telegram Publisher)]

-Vara:

Argentina	34.0944"
Costa Rica & El Salvador	32.913"
Guatemala	32.909"
Honduras	32.874"
Nicaragua	33.057"
Chile & Peru	32.913"
Cuba	33.386"
Mexico	32.992"
Spain	32.90976"

-Pie:

Argentina	0.9471′
Spain	0.91416′

Theory

The pie reale of Spain is close to the pied de roi of France. If the Castilian foot predates the royal foot then it is possible that the royal foot derives from France, altered to fit the 6 to 7 ratio with the Castilian foot. However, if a value of 17/24 of the Paris ell (see C of A & S-1752) is taken for the Castilian foot then this value would be close to that of the "pied de roi" or 1.0663′ between the 1752 value for the Paris foot of 1.068′ and the 1753 value of 1.0658′.

Spanish Linear Measure

144 puntos = 12 linas = 1 pulgada

12 pulgadas = 2 sesmas = 1 pie

12 pies = 4 varas = 2 tuesas = 1 estadal

1 palmo = 3/4 pie; 1 Legua = 8000 varas

Equivalents (Castilian measurement in feet and inches)

1. Chambers, Cyclopedia of Arts and Sciences (1752)
   1 vara (Almeria) = 33.12", 1 pie = .9253"
   1 vara (Aragon) - 5.815′

1752

[E. Chambers, Cyclopedia of Arts and Sciences]

-The Spanish Measure is the vara, or yard, in some places called the barra; containing seventeen twenty-fourths of the Paris ell [32.895"]. But the measure in Castile and Valencia is the pan, span or palm; which is used, together with the canna, at Genoa. In Aragon, the vara is equal to a Paris ell and a half; or five feet [Paris], five inches, six lines.

-Paris royal foot = 1.068′ (1.0654′)

-The vara of Almeria and Gibraltor in Spain = 2.760′ = 33.12" (1 pie = .92′]

-The palm of Genoa = 0.815′ [pie = 1.087′ if palm = .75 pie]

-The yard (English) contains three feet; equal to 7/9 of a Paris ell [2.816 Pf.] The (French) ell equals 3 Paris feet, 7 inches, 8 lines; or 1 yard, 2/7 English.

-Ell - standard cloth measure.

English = 3′-9" or 1.25 yards [3.75′ or 45"]
French = 1.29 yards [3.87′ or 46.5"]
Flemish = 27 inches or .75 yard [2.25′]

1753

[Supplement, Cyclopedia of Arts and Sciences]

-Paris foot contains 12.785 English inches; or 1 Paris foot = 1.0654′

-Vara (1752) - .7083 Paris ell or 32.953" [Pe = 46.524" or 3.877′]

-Vara (Aragon-1752) = 1.5 Paris ell or 5.815′

1872

[American Cyclopedia]

-Genoa - palmo = .8173′, piede manuale = 1.226′ [palmo = 2.3 piede manuale] piede liprando = 1.6857′ [pie r. (based on palmo - 3/4 pie) = 1.0897′ (1/x = .9177, pie c. = .937′]

-France (old system)

-144 lignes = 12 pouces = 1 "pied de roe"=12.79" (1.06583′); 6 pieds - 1 toises

2. Gallier, The American Builder's Price Book and Estimater (1833)
   1 pie (Spain) = .9268'
   1 vara (Spain) = 33.365"

3. Appleton's Dictionary of Engineering (1852)
   1 pie (Spain) = .9195'
   1 toesas (Spain) = 66.72"

4. American Cyclopedia (1871)
   1 pie (Spain) = .9273', 1 vara (Spain) = 33.383"
   1 pie (Cuba) = .9258', 1 vara (Cuba) = 33.333"
   1 pie (Mexico) = .9158', 1 vara (Mexico) = 32.97"

5. Encyclopedia Britannica (1901)
   1 pie (Mexico) = .9158', 1 vara (Mexico) = 32.97"

6. The World Almanac (1949)
   1 pie (Mexico) = .9164', 1 vara - 32.992"
   1 pie (Cuba) = .9274', 1 vara - 33.386"
   1 pie (Spain) = .9142', 1 vara - 32.91"

*** Conversion factors: (From scales on eighteenth century drawings.)

-Castilian to Royal = .8571'

-Royal to Castilian = 1.167'

-Pie (Castilian) = .927', vara (Castilian) = 33.4"

-Pie (Royal) = 1.08', vara (Royal) 38.98"