# Fort Sumter
# Fort Sumter National Monument

# Historic Structure Report

## Volume II
### APPENDICES A-F

2015

for

**Cultural Resources, Partnerships, and Science Division**

**Southeast Region, National Park Service**

by

**JOSEPH K. OPPERMANN – ARCHITECT, P.A.**

539 N. Trade Street    Winston-Salem, NC 27101

www.jkoa.net    336/721-1711

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# Appendix A: Glossary

The glossary contains terms that may be unfamiliar to the reader. Some definitions have been adjusted to reflect conditions specific to Fort Sumter.

# Glossary

**AMTB:** Anti Motor Torpedo Boat.
**Ammunition Hoist:** Elevator to lift shells from storage magazine to cannon.
**Angle:** A place where a fort wall abruptly changes direction.
**Artificial Stone:** Cast concrete made to simulate natural stone.
**Barbette Battery:** A group of guns aligned to fire over the parapet of a fort.
**Barbette Tier:** The uppermost level of guns in a multistory fort.
**Barracks:** Structures for housing troops.
**Battery:** A group of guns operating in concert.
**Bedding Mortar**: The mortar used to construct a masonry wall as opposed to pointing mortar used to dress the outer surface of a masonry joint.
**Bluestone:** A naturally occurring stone, blue- grey in color. It is easily cut which makes it ideal for floors and walkways.
**Bushel:** A unit of measure equivalent to 1.24 cubic feet.
**Caliber:** The diameter of the bore of various artillery and their projectiles.
**Carriage Tongue**: A metal plate extending from the front of a gun carriage assembly, designed to anchor the chassis to a protective wall while allowing the carriage to be moved in a horizontal arc.
**Casemate:** Chamber within the walls of a fort generally used as a gunroom, and pierced with an opening ("embrasure") through which a cannon could fire. A casemate could also be used as quarters, powder magazine, or for other purposes.
**Casemate Arch:** A masonry feature connecting the front and rear piers of a casemate.
**Casemate Carriage:** A form of gun carriage specifically designed to operate in a casemate.
**Casemate Vault:** The ceiling of a casemate.
**Charleston Grey Brick:** Bricks made in the lowcountry region surrounding Charleston. The Wando clays from this region are grey in color when dried. They form a reddish brown brick when fired and typically have numerous iron-rich black silicone inclusions (chert).
**Chert:** A microcrystalline sedimentary rock.
**Circle or Traverse Circle:** Granite arc flooring segment to support iron traverse rails (see) to prevent the wheels of a gun carriage from sinking.
**Cistern:** A structure designed to store fresh water.
**Columbiad:** A type of heavy smoothbore cannon invented in 1811 by Col. George Bomford.
**Concrete:** A construction material composed of a binder and large and small aggregates. The binder can be lime, natural cement, Portland cement or mixtures of these materials.
**Coping:** The cap or cover on a wall.
**Counterfort:** An inner buttress used to strengthen the masonry of a ramparts revetment.
**Counterscarp:** An additional reinforcing wall constructed on the exterior of the scarp wall.
**Embrasure:** Opening in an outer casemate wall through which cannon fire, typically splayed to increase the angle of fire and to maximize protection.
**Embrasure Arch:** An arched masonry element above an embrasure.
**Esplanade:** A long, open, level area next to a body of water.
**Escarpment:** The foreground of a fortification, excavated precipitously to hinder an enemy's approach.
**Face:** The two defensive perimeter walls of Fort Sumter that join to form the salient angle. Each face meets the adjoining flank wall at a shoulder angle.
**Flank:** The two parallel defensive perimeter walls of Fort Sumter, lying between the rear gorge wall and the corresponding flank wall.
**Flat Boat:** A rudimentary boat of shallow draft for transporting material.

**Gabions:** Large cylinders, generally of wicker, filled with sand, earth, or rubble and used for protection against artillery fire.
**Gallery:** Roofed passage area open except at the back wall.
**Garrison**: A complement of men and officers manning a fort.
**Gorge:** The rear wall of the fort adjacent to the officers' quarters and, at Fort Sumter, the principal powder magazines.
**Grillage:** A network of logs or beams laid horizontally for use as a foundation.
**Gun Platform:** An unroofed platform built to provide an area for the cannon of a fortification. The gun platform reduced the noise and fumes of a confined space but left the gun crew more exposed to incoming fire.
**Hot Shot:** Cannon balls (solid shot) heated in a shot oven or hot-shot pit and fired, generally at enemy ships to set them on fire.
**Howitzer:** Short-barreled cannon that fire shells, solid shot, case shot, grape, and canister at a high trajectory with a steep angle of descent.
**Lintel:** A horizontal member that spans the top of an opening, such as a door or window.
**Lights (front and rear lights):** Stationary navigational lights to guide ships through the harbor.
**Magazine or Powder Magazine:** A room or compartment for the storage of gunpowder.
**Mechanics:** Skilled artisans and tradesmen.
**Mole:** Underwater construction of stone laid directly on the shoal to form the foundation of the fort.
**Mortar (masonry):** A mixture of sand and a binder used to join masonry units. Common binders are hydrated lime, hydradraulic lime, natural cement, Portland cement, or mixtures of these materials.
**Mortar (artillery):** A short-barreled cannon designed to shoot shells or hot shot in a high arcing fire.
**Mouth:** The narrow interior opening of an embrasure.
**Natural Cement:** A cement produced by calcification of crushed carbonate sedimentary rocks in kilns.
**Ordnance:** Military supplies, especially weapons and ammunition.
**Parade or Parade Ground:** Open area at the center of the fort where troops were assembled for drills or inspection.
**Parapet:** A low wall at the top tier of a fort designed to screen soldiers from enemy fire and to provide protection for cannon.
**Parging:** Smooth thin stucco used to cover the brownstone and granite elements in the casemates.
**Platform:** Foundation, usually built of timber, that supports an artillery piece to prevent it from miring into the dirt surface of the terreplein.
**Pointing Mortar:** A mortar used to fill the exterior joints of a masonry wall. Although often used for decorative purposes, its primary function is to limit water intrusion into the masonry.
**Portland Cement:** A cement that hardens under water and is made by heating a slurry of clay and crushed chalk or limestone to clinker in a kiln.
**Postern or Postern Gate:** A small secondary entrance.
**Rampart:** Embankment around a fortified position, generally of earth, brick, or stone.
**Redoubt:** An earthwork of one or multiple walls, generally not enclosed,
**Repointing:** Replacement of the outer ("pointing") mortar of masonry joints.
**Rosendale Cement:** A natural cement produced from a dolostone, rich in magnesium and clay, from the Rosendale area of New York. It was very popular for its durability. By 1930, it was generally replaced by faster curing but less durable Portland cement.
**Revetment:** A facing of masonry or the like, for protecting an embankment from the energy of incoming water. Also, a retaining wall or facing of wood, masonry or other material, supporting or protecting a rampart, wall, etc.
**Salient Angle:** The forward projecting point formed by the two face walls of a fort.
**Sallyport:** The main entrance to the interior of a fort.
**Scarp:** An exterior wall of a fort.

**Service Magazine:** A small magazine designed to hold a limited amount of ammunition near a gun position.
**Shell:** A hollow form of projectile containing an explosive or flammable material.
**Shot:** A solid form of projectile.
**Shoulder Angle:** The angle at the intersection of a face and flank wall of a fort.
**Sill:** A horizontal member at the bottom of an opening such as a window.
**Stores:** Supplies.
**Tabby**: A form of concrete made with sea shell (typically oyster), sand, and lime (typically from burnt oyster shell).
**Terreplein:** Gun position on the top level of a fort.
**Tiers:** Levels in a fort.
**Tongue Hole:** The narrow slot directly under the embrasure that received the tongue of the gun chassis, also known as a rotating slot.
**Traverse Rails:** Semicircular flat iron plates upon which the wheels of a supporting chassis of a gun carriage move.
**Turn, Turned:** Construction of arches.
**U-boat:** German submarine.

# Appendix B: Documentation Drawings: As-Found

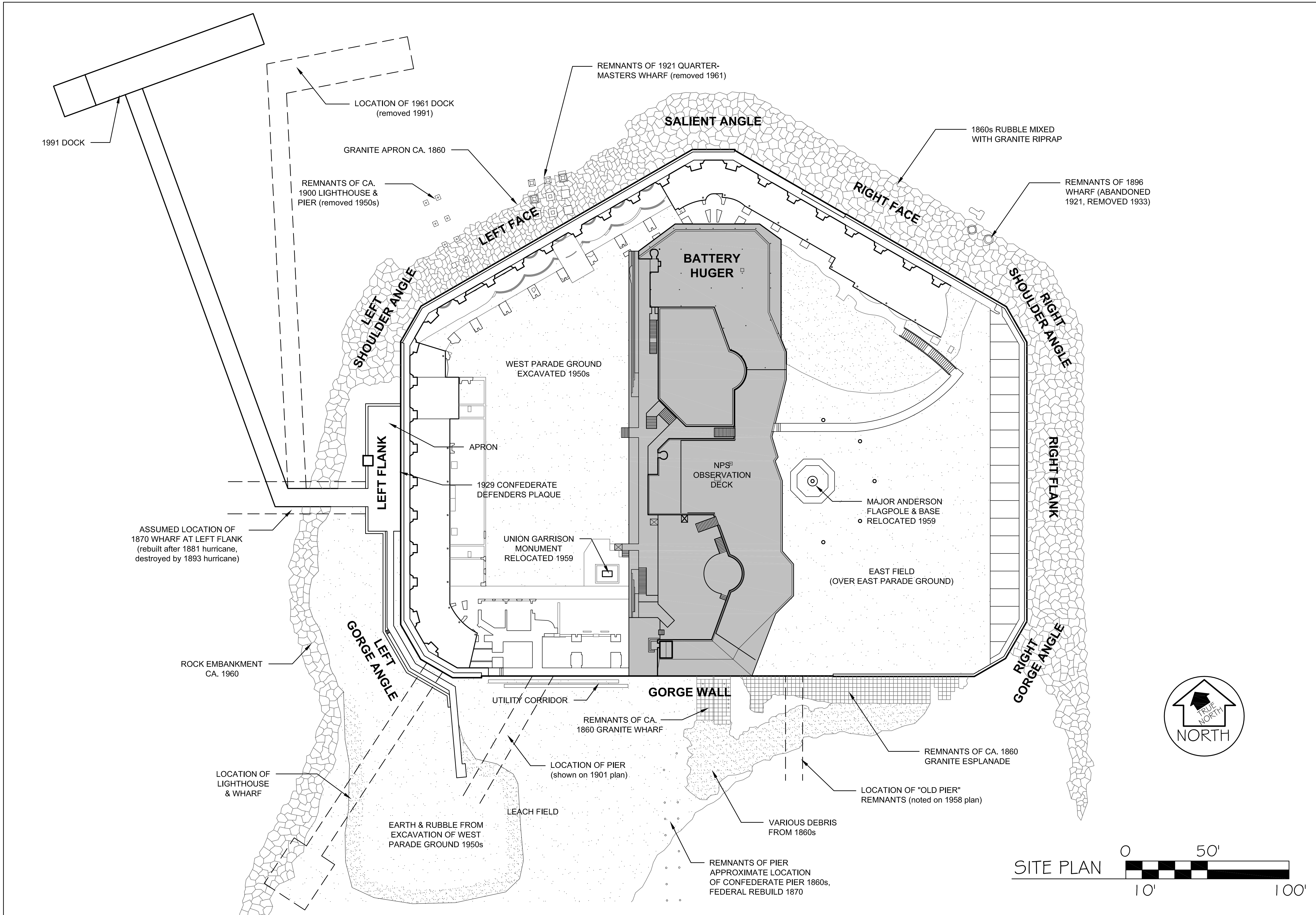
Sheet B-1: Site Plan
Sheet B-2: Ground Floor Plan
Sheet B-3: Second Floor Plan
Sheet B-4: Roof Plan

Two distinct sets of As-Found Documentation were prepared for this project. The first set of documentation was prepared by Joseph K. Oppermann – Architect, P.A. and consists of digital line drawings of plans in AutoCAD, including both Fort Sumter and Battery Huger. The four drawings in this set are included in this Appendix: B-1 Site Plan with notations to orientate the viewer to the principal parts of the buildings and site, as well as the locations of significant cultural and operational features associated with the development of the site; B-2 Ground Floor Plan with the accessible casemates of the original Fort Sumter and Battery Huger delineated, the Fort Sumter casemate numbers assigned according to the HABS drawings of the 1990s, and the rooms of Battery Huger receiving new numbers; B-3 Second Floor Plan continues the room enumeration of Battery Huger; and B-4 Roof Plan with notations identifying significant features of Battery Huger at roof level.

The buildings and site were measured by hand using tape measure and digital Leica Disto measuring instrument during early field investigations. The field measurements were converted to these AutoCAD drawings. The scaled drawings in AutoCAD were used in the field to identify the location and extent of conditions.

A second set of As-Found Documentation consists of 41 pages of hybrid images that record the exterior face of the perimeter wall of Fort Sumter as well as the exposed interior face and the exterior west elevation of Battery Huger. These images are digitally recorded in high resolution photogrammetry overlaid with scaled line drawings in AutoCAD. These hybrid images were recorded by Aaslestad Preservation Consulting.

There are multiple purposes for these images, which in themselves provide a detailed visual record of the subject wall surfaces at the time of recording. First, they are a valuable tool for use in the field for recording conditions (as in Appendix D). Second, as a comprehensive record of conditions at a specific point in time, they can be compared to future recordings to gauge change. And third, the images can be used in future phases to prescribe repairs and conservation treatments in precisely specific locations. Each page of this documentation has an identification number that corresponds to a location key on a small building plan at the bottom center of the page; the identification number corresponds to the location on the building where the images were recorded. A DVD containing the entire set of 41 pages is included with the final HSR.

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# FORT SUMTER

CHARLESTON HARBOR, SOUTH CAROLINA

U. S. DEPARTMENT OF THE INTERIOR - NATIONAL PARK SERVICE

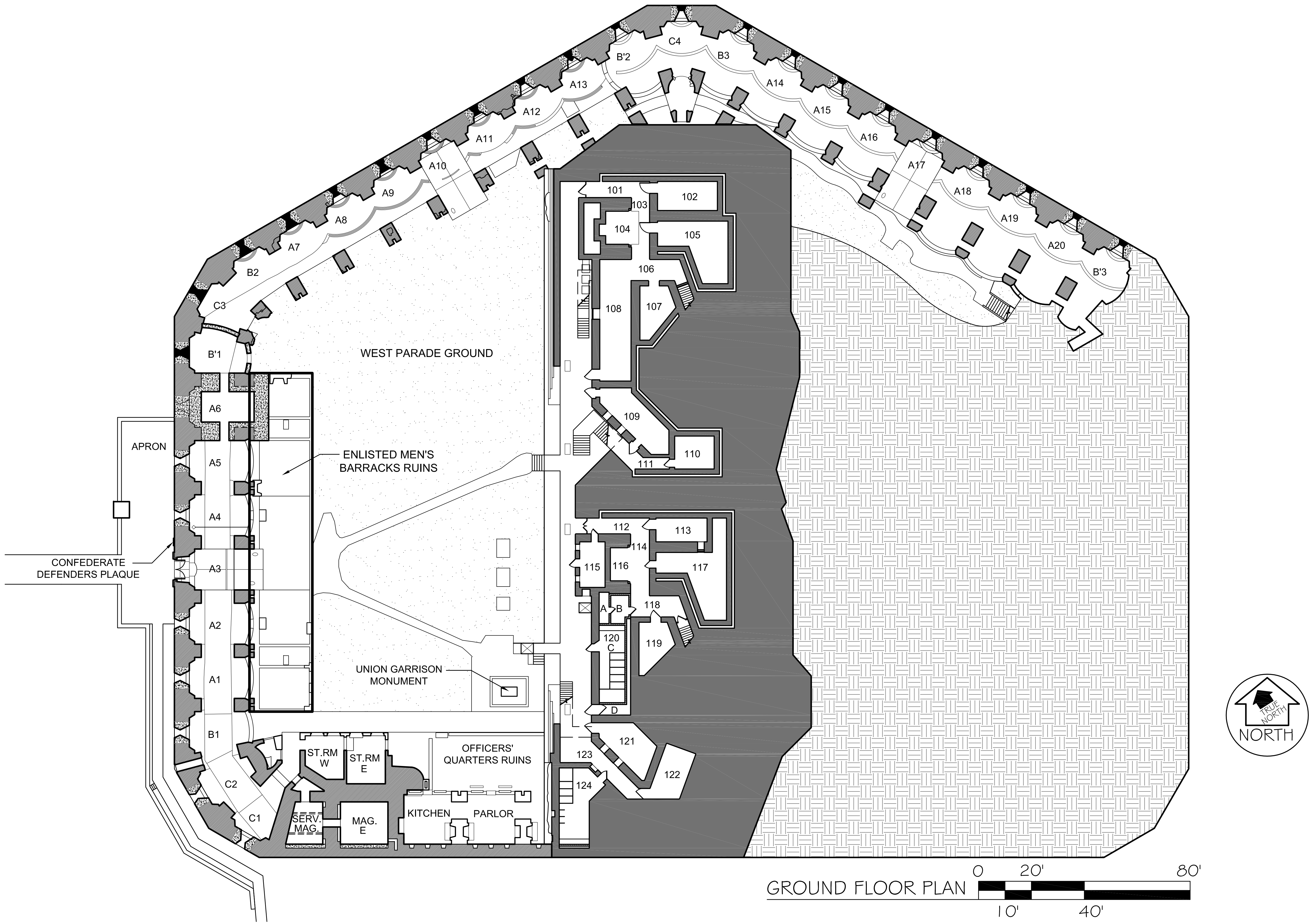
RECORDATION DATE:
04.10.2014

RECORDED BY:
JKO
RLM

SCALE:
not to scale

HSR
APPENDIX B:
SHEET

B-1

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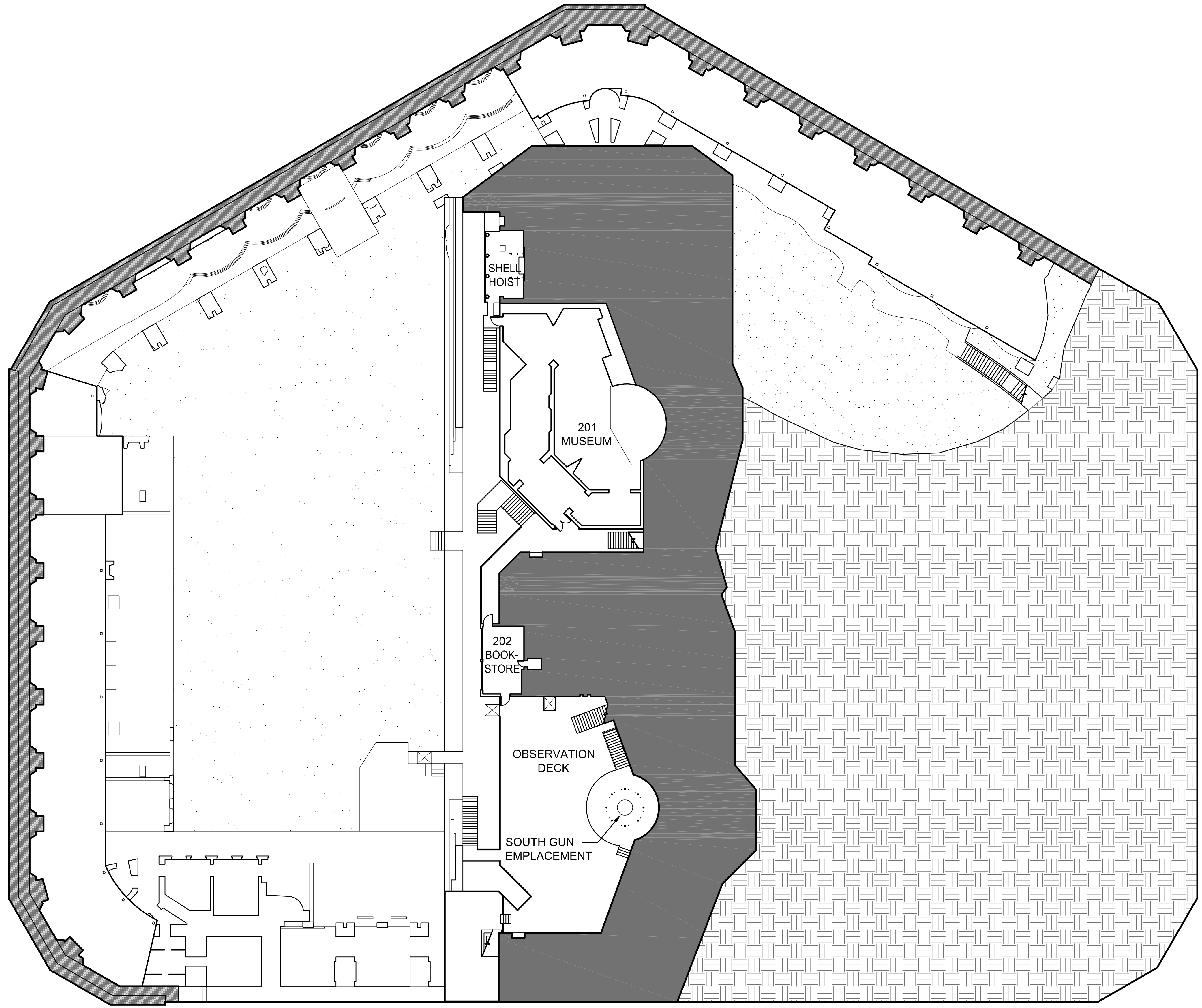
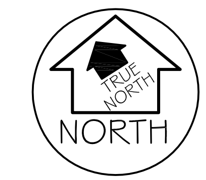
APPENDIX B:
SHEET

# B-2




SECOND FLOOR PLAN

0 20' 80'
10' 40'

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WINSTON-SALEM, NORTH CAROLINA

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CHARLESTON HARBOR, SOUTH CAROLINA

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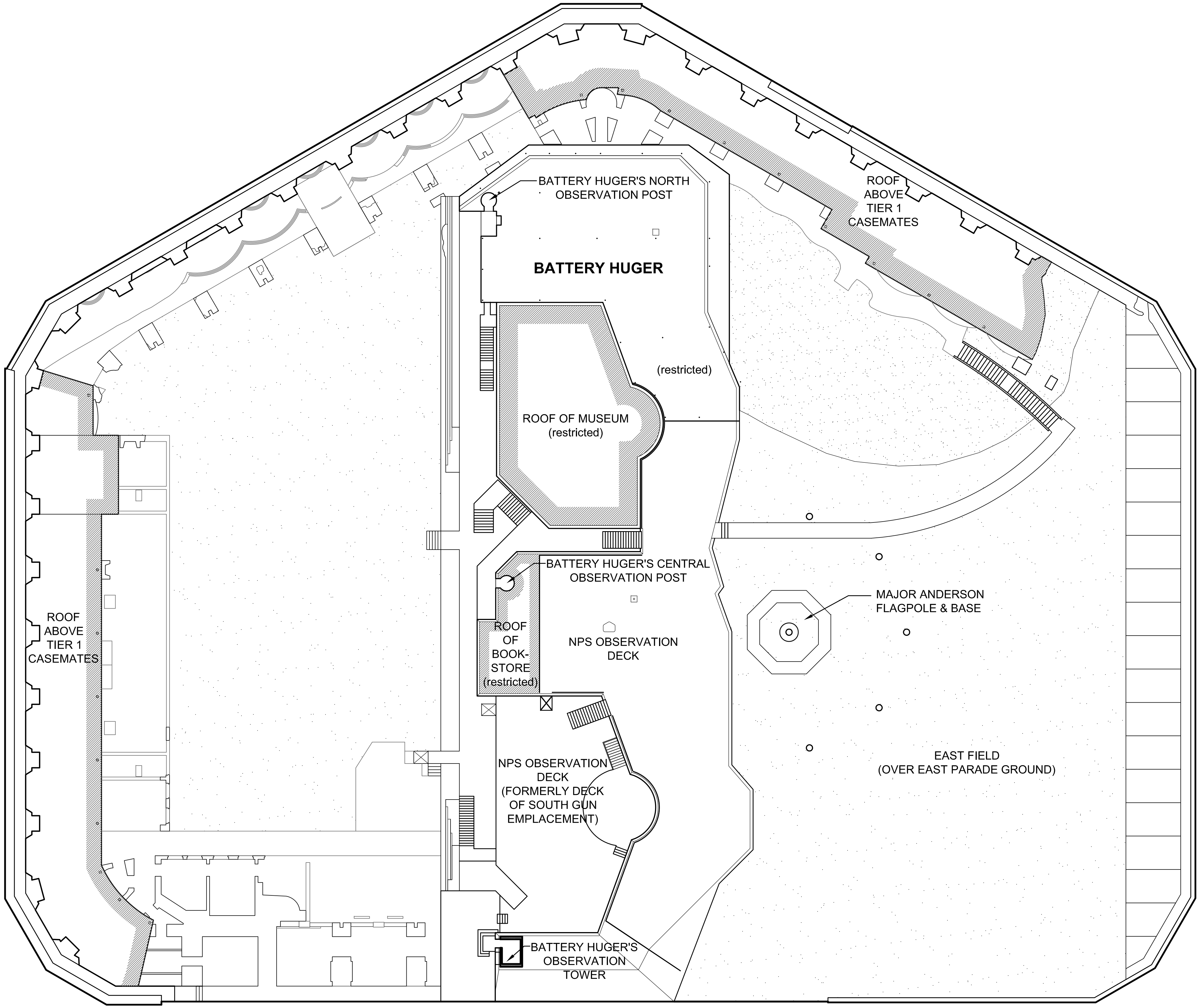
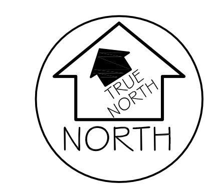
APPENDIX B:
SHEET

B-3




ROOF PLAN

0 10' 20' 40' 80'

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WINSTON-SALEM, NORTH CAROLINA

# FORT SUMTER

CHARLESTON HARBOR, SOUTH CAROLINA

U. S. DEPARTMENT OF THE INTERIOR - NATIONAL PARK SERVICE

RECORDATION DATE: 04.10.2014

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SCALE: not to scale

HSR APPENDIX B: SHEET

B-4

# Appendix C: Report on Structural Issues

The following appendix is a report on structural issues at Fort Sumter prepared by structural engineer Craig Bennett, PE of Bennett Preservation Engineering, Inc. It includes a review of the recently completed Atamturktur/Prabhu report (Clemson University). The Bennett report concludes with recommendations for additional actions to be implemented.

STRUCTURAL ENGINEERING FOR EXISTING STRUCTURES
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**A Report on the Structural Issues at**

# Fort Sumter National Monument

Charleston, South Carolina

May 1, 2015

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In 2011, Joseph K. Oppermann of Joseph K. Oppermann, Architect asked Craig M. Bennett, Jr. of Bennett Preservation Engineering PC to assist with the structural conditions assessment portion of the Historic Structure Report for Fort Sumter National Monument. Oppermann was preparing the report for the National Park Service.

As Bennett had previously prepared a simple, very limited report for the Third System Coastal Defenses portion of Fort Sumter (i.e. the mid-19th century brick masonry pentagon), more of the field work for this second, more extensive report was focused on the evaluation of the Endicott Battery (Battery Huger) placed inside the walls of the Third System pentagon. The two forts, Third System and Endicott, are treated in this report almost as independent structures, except where one influences the other structurally. Findings, conclusions and recommendations on the two systems are presented sequentially.

The findings of this report are those found during eight site visits, all specifically aimed at evaluating the structural condition of the two systems. The report discusses areas of structural distress and notes several areas of concern where further study is warranted to determine severity and to develop appropriate mitigation techniques.

The report is further based on the study of structural drawings, on participation in several workshops on the behavior of the fort and its materials, on a review of a number of other reports on Fort Sumter, on the author's structural work on and nine site visits to Fort Washington and major structural work on and ten site visits to Fort Jefferson (both Third System fortifications), on the author's study of two other Third System fortifications (Fort Clinch and Fort Zachary Taylor), on the author's visits to three other Endicott batteries (Fort Washington, Fort Moultrie, and Fort Fremont), and finally on the author's multiple reports and publications on the structural behavior of Fort Jefferson National Monument.

Several documents were provided by the National Park Service. These documents were of help in understanding some of the most recent studies of Fort Sumter. The documents provided include:

- Selected architectural drawings (1845-1991)
- Endicott Construction History, Charles W. Snell (1975)
- Historic Structure Report on Battery Isaac Huger, Charles W. Snell (1977)
- Settlement Survey, Michael Shulse, PLS (1992)
- Structural Monitoring Report, Law Engineering (1992)
- Battery Huger Foundation Investigation Report of Investigation and Analysis, U.S. Army Corps of Engineers (1992)
- Armor Stone and Outer Wall Structural Study, NPS and US Army Corps of Engineers (1998)
- Submerged Cultural Resources Survey of Proposed Breakwater Construction Project Area, NPS and US Army Corps of Engineers (2001)
- Settlement Survey, Michael Shulse, PLS (2006)

- Site Visit Report, Gregory A. Hider, PE (2006)
- Historic Structure Report on Fort Hancock, New Jersey, James J. Lee III and Lauren Laham (2007)
- A Structural Issues Report, Craig M. Bennett, Jr., PE, 4SE Inc. (2009)
- Observations on Fort Sumter by Dorothy S. Krotzer, BCA (2009)
- Comments Based on an Examination of Endicott Battery Historic Concrete, Toy Poole, Ph.D. (2010)
- Fort Sumter Masonry Conditions, Structures North Consulting Engineers, Inc. (2010)
- Structural Analysis of Fort Sumter National Monument Final Report, Sez Atamturktur, Ph.D. and Saurabh Prabhu (2013)
- Report on Deformation Survey Performed at Fort Sumter, Peter Messier, PLS, PE (2013)
- The Structural Assessment of Subterranean Cisterns, Sez Atamturktur, Ph.D. and Saurabh Prabhu (2013)
- Final Report on Deformation Survey Performed at the Fort Sumter National Monument, Peter Messier, PLS, PE (2013)

The on-site inspection was limited to visual observations and measurements of the interior and exterior of the fort, including both Third System and Endicott fortifications. The recommendations in this report note several areas requiring further study. Some of this work has been done by others, on our recommendation but not under our control. Much of that work has been made available to Bennett Preservation Engineering.

This report acts as an aid to the National Park Service in determining a strategy for protecting the fort from further deterioration and for increasing the level of protection of its many visitors. In a few instances, this report also discusses the need for immediate repairs in certain areas. These recommendations for immediate repair address issues that could threaten the safety of Fort Sumter's employees and visitors.

Construction of Fort Sumter began in 1829 and was essentially complete by the start of the Civil War in 1861. The fort is a pentagonal brick and oyster shell concrete structure on a foundation of cut stone set on stone rubble on a sand bar at the entrance to Charleston Harbor. (Figure 1) Fort Sumter was originally a three-tiered structure, but suffered severe damage during the Civil War. After the war, the fort was partially rebuilt. Battery Huger, the Endicott fort built in the interior of the Third System pentagon, was added during the Spanish-American War. Fort Sumter became a National Monument in 1948. More complete histories can be found in other sections of this Historic Structure Report, in the National Park Service archives, and at the Library of Congress.

The pentagonal brick masonry section of Fort Sumter is an example of the design and construction typical of Third System coastal defenses (Figures 2 and 3). The rampart consists of several elements. The first, a scarp wall, forms the perimeter of the fort. Embrasures (many now bricked in or covered) were built into the scarp to allow cannon to fire. The remainder of the rampart is formed by the casemates. These are located between the parade wall arcade and another series of arches along the interior of the scarp wall that frame each embrasure. Every casemate is vaulted, with the vaults resting on arched abutments that extend from the arcade piers. As shown in Figure 2, the arcades, vaults, and scarp are not tied together, but are, in fact, separate structural systems. However, compression loads are transferred between these systems through direct contact.

When Fort Sumter was partially rebuilt in the 1870s, the upper tiers were eliminated (Figure 2). The casemates along the right face and right flank were covered with earth fill, though the interior of the right face was excavated in the twentieth century. The exposed vaults are now covered with a concrete roof, which was added as protection against water intrusion.

The Endicott era concrete section of the fort, Battery Huger, was built within the walls of the Third System pentagon. The mass concrete was poured in individual lifts, supported in some areas on steel framing and in others directly on grade. The steel support columns, where used, provide significant structural support for the mass concrete. The girders and joists originally provided support for the concrete, but, with the concrete now being of great depth and having tremendous stiffness if not strength, likely are of limited value.

As previously mentioned, we have, in a series of site visits covering work done under this and previous contracts, observed all accessible areas of Fort Sumter. The purpose of these site visits was to provide a close look at structural issues at the fort so that we could report on current structural conditions and issues, determine the need for additional study, and recommend repairs. In some of those earlier contracts, we were asked to consider whether the granite revetment should remain or be modified, whether the foundation and above-ground vaults were performing as required or were compromising the structural integrity of the fort, and finally, to consider which in-depth methods of structural assessment would best evaluate current structural stability and aid in determining the need for repairs for long term stability. In the more recent visits, we were asked to present findings, conclusions and recommendations on the Third System fort as a whole and on the Endicott battery.

**Third System Brick Masonry Pentagon**

During our site visits, we have inspected both the interior and exterior walls of the Third System fort. The exterior examination was conducted at low tide to maximize visibility of potential structural issues and damage to the scarp. The interior examination was focused on the vaulted arcades along the perimeter walls.

The examination of the exterior walls revealed several categories of damage:

- Superficial damage, including surface erosion of bricks, mortar, and concrete,
- Bowing out of the walls as they approached each corner of the fort,
- Deep fractures through the scarp, and
- Structural movement indicative of the failure of the vault and arch systems.

Erosion along the exterior scarp wall varies across the fort. Along the base of the wall, uniform softening and erosion of mortar has occurred below the high water mark (Figure 4). Erosion is most severe where granite revetment blocks rest against the wall (Figure 5). Above the high water mark, erosion of the face of the wall is most severe on the salient, right face, and right flank, areas which face the shipping channel (Figures 6 and 7). In some locations, previous repointing with a hard Portland cement has accelerated the loss of the brick face (Figure 8). Loose bricks along the cornice were also noted along the exterior (Figure 9).

To varying degrees, the long walls of the fort bow out as they approach the shoulders, gorge angles, and salient. This is clearly discernible in Figures 10 through 14. In these photographs, there is an obvious curvature of the mortar lines between courses of brick, indicating that the walls themselves are bowing along that arc.

Several masonry cracks were found along the exterior of the fort. The cracks are located towards the ends of the long walls and on the shoulders (Figures 14 through 19). Several of these cracks extend from the top of the wall to below the revetment. Others start at the top of the wall and stop at a corner before reaching the base of the wall. The right face and right flank contain the majority of the cracks noted on this site visit.

Inside the fort, much of the visible damage consists of cracked arches and vaults. A number of vaults in the arcades are cracked, especially at the ends of each arcade (Figures 20 and 21). Many of vault-supporting arches are also cracked; both vertical and horizontal cracks were found in a significant number of these arches (Figures 22 and 23). Some of the thrust resisting abutments also show signs of movement (Figure 24).

Each of the casement vaults that were examined as a part of this site visit has a crack running perpendicular to its axis (Figures 22 and 23, 25 and 26). The cracks are of varying sizes, and vary in location slightly, but tend to be close to the middle of the vault. In one vault along the right face, cracks run in both directions, and one section of the vault is dropping below the rest (Figure 27). Many of the cracks in the vaults have been filled with epoxy, mortar or grout (Figures 25 and 26). In some locations, the filled crack has reopened or a new crack has formed adjacent to the repair (Figure 26).

Other masonry cracks can be found throughout the fort (Figures 28 and 29). These will require evaluation individually to determine their cause and to determine whether the damage represents a common cause of structural distress.

Also noted during the course of the field work were two issues that present life safety concerns. Loose bricks along the edges of broken vaults, arches, and the cornice can and regularly do fall, risking injury to a visitor or employee (Figures 9 and 30). Also, cracks in the granite over the cistern near the left face indicate that there is the possibility of localized catastrophic failure (Figure 31). Visitors are currently allowed to walk over and stand on this cistern, but should not be. These two issues are addressed in particular in the "Recommendations" section of this report.

**Endicott Era Battery Huger**

In several site visits, we have additionally inspected as much of the Endicott era Battery Huger as was accessible.

The examination of Battery Huger also revealed two general categories of damage:

- Fracture of the unreinforced concrete, and
- Corrosion of the steel.

The fracture of the unreinforced concrete is most easily seen in the west wall of Battery Huger near ground level (Figures 34 through 41). Here one sees vertical fractures indicative of vertical movement of the middle portion of the walls relative to the north and south ends. Unfortunately, the 2006 Settlement Survey, comparing 1992 and 2006 settlements, was not able to confirm this behavior

because the survey bolts along this wall were destroyed between 1992 and 2006. Fortunately, the 2011 and 2012 surveys reported by Messier in 2013 are both accurate and robust. We have high hopes that, in the future, the Messier survey system will allow excellent determination of both horizontal and vertical movement of portions of the fort relative to each other.

Corrosion of the supporting steel in Battery Huger is pervasive and, unfortunately, largely inaccessible. The columns generally are at least partially embedded in concrete and the girders and joists have significant portions embedded. Corrosion of the embedded portions is, in some areas, causing major damage to the concrete through corrosion jacking (Figures 42 through 47). It additionally suffers significant loss of section in the more exposed areas (Figures 50 through 52).

One final additional failure is seen in the two-way concrete pan joist system of the roof of the museum on top of Battery Huger. The two-way concrete pan joist system has fractured in the positive moment regions, in a manner consistent with structural overload. (Figure 53)

**Life Safety Findings**

Noted during the course of the observations were three structural issues that present immediate safety concerns.

First, loose bricks along the edges of broken vaults, arches, and the cornice could fall, injuring a visitor or employee (Figures 9 and 30). Secondly, pieces of concrete broken by corrosion jacking of the embedded steel in the Endicott battery pose a similar threat. (Figures 42 through 47) Finally, cracks in the granite over the cistern near the Left Face indicate that there is the possibility of localized catastrophic failure (Figure 31). On our most recent site visits, visitors are allowed to walk over and stand on this cistern, but should not be. These three issues are addressed in particular in the "Recommendations" section of this report.

**Third System Brick Masonry Pentagon**

Erosion of mortar and the outer wythe of bricks is a threat to the long term health of Fort Sumter. This erosion has been caused by sand and other debris carried by wind and water. The subsequent damage to the surface allows for the introduction of excess water and chlorides to the inner wall, eventually weakening the wall and leading to structural distress. In several places, mortar that is too hard and too impermeable has accelerated the erosion of the face of the brick (Figure 8). In other places, mortar that is too soft has disintegrated, leaving large gaps between bricks, compromising the structural integrity of the outer skin of bricks and allowing water behind it (Figure 7).

Additional erosion has also occurred at the base of the wall, where continued exposure to water has eroded the mortar (Figure 4). In locations where the granite blocks of the revetment touch the brick wall, erosion has been accelerated by contact (Figure 5). Mechanical erosion caused by acceleration of water put in motion by wave action likely also contributes to the heavier areas of damage. These two factors would account for the large discrepancy in the speed of brick and mortar erosion in these locations versus areas where the granite does not touch the bricks. Furthermore, the granite blocks make it difficult to repair the bottom portion of the wall, so erosion has never been slowed by repointing.

Although additional structural modeling is required to be certain of the structural behavior of the scarp and the casemates, the bowing of the exterior walls of the fort at the salient shoulder and gorge angles appears to be the result of the unresisted thrust of the arcades along the interior, and is exacerbated by moisture-fueled brick expansion. As each arcade reaches its end at the fort's shoulders, the thrust is not adequately counteracted, and therefore pushes the walls outward, allowing the arches near the ends to break. The cracks along the exterior walls are seen mostly at the ends of the walls, which is further indication that the arcades are the cause of distress. In addition, newer bricks in areas of reconstruction (Figures 32 and 33) may have caused damage through differential expansion, as these sections would have grown relative to the older brick. Other cracks may be caused by interior drainage elements, stress from expanding brick and deteriorated mortar, or weight from the earth on the interior of the fort along the right flank and right gorge.

Cracks observed on the interior supporting arches are due to their supporting elements (piers, abutments, and perimeter walls) not adequately resisting the thrust of the arches and vaults. Many of these cracks can be found near the end of arcades or where an arcade has been broken by demolition. One good example of this phenomenon is illustrated by Figure 24. This arch is broken in two locations. In this particular case, the structure once giving additional stiffness to the interior abutment has been destroyed, weakening the system. The exterior abutment is located at the salient wall and at the end of an arcade, where resisting forces are weakest. Furthermore, a large horizontal crack through the upper abutment on the exterior side illustrates the force of the outward thrust of the arch. While this example of vault support movement is extreme, similar damage was observed throughout the fort.

The cracks noted in the vaults generally result from the movement of the vault supports, causing the vaults to try to act as flexural members spanning between the inner and outer arcades rather than acting as compression-only elements, as originally intended.

Loose bricks in several locations throughout the fort present a threat to life safety. The broken vaults along the left face are prime locations for this problem. The cornice also shows signs of distress in many locations. Though visitors are not allowed on the revetment, employees and workers hired to repair damage on the wall will be subjected to the danger from falling bricks. Finally, the cistern tops show signs of failure and potential collapse.

**Endicott Era Battery Huger**

The weight of the concrete of Battery Huger certainly has the potential to cause settlement damage to the Third System brick masonry pentagon. A new survey of the 1992, 2006 and 2011 survey points and markers could give a better indication as to how much of a problem that is.

The corrosion of the embedded steel will ultimately continue to damage more and more resources. We have seen other Endicott era batteries (Fort Fremont) where, because of the stiffness and depth of the supported concrete, the loss of the joists and girders has not caused major structural distress. But we are confident that such deterioration cannot be safely tolerated long term.

**Third System Brick Masonry Pentagon**

Of utmost concern are any elements that compromise life safety at the fort. We recommend that all bricks that are held in place only by tension or shear stress in the mortar be regularly checked for a tight bond to the substrate, that all loose bricks be carefully removed and stored for use in future repair work, and that any cracks through the cornice or around single or small groups of bricks must be monitored for loosening. We also recommend that all cisterns with fractured granite tops be blocked off so that visitors cannot stand on them until they have been strengthened.

We recommend that eroded joints on the scarp be repointed and missing or severely deteriorated bricks be replaced. Granite blocks along the revetment that touch the exterior wall should be permanently moved away from the wall, but should remain part of the revetment. Blocks that prevent repair to the base of the wall should be moved back from the scarp while repairs are conducted. These can be placed back in their original locations once repairs are completed, or they may be rearranged to facilitate future repairs.

Although the question has been asked, given the limited scope of this report, we are not prepared to make a recommendation on the permanent removal of the revetment. Further studies, including hydrological studies, will be needed before a decision on the removal of the revetment is made.

Further studies are also recommended before deciding on a treatment approach to correct structural problems present in the rampart, foundations, cisterns, and in Battery Huger. Given Fort Sumter's location in Charleston Harbor and current conditions, such as the presence of the fort's interior earth fill and the distorted geometry of the scarp, better base information will be required to generate the best information from additional studies.

We have studied the information made available to us. In order to assist in developing recommendations regarding both the structural movement of the salient, the two shoulder angles and the two gorge angles, and to better understand the damage caused by Battery Huger and the earth fill east of it, we recommend that:

- The surveys made in 2011 and 2012 be repeated,
- The 2006 survey be repeated,
- The elevation of a single mortar joint single mortar joint be traced completely around the fort, and
- Finally, we recommend that a network of very accurate (5 to 10 micrometers) electronic crack monitors, backed up by stainless steel or bronze cross-crack measurement points, be installed around the fort, with the monitoring system able to record crack widths to the Web on an hourly basis with the intention that the data be thoroughly evaluated annually.

  Such monitors would provide information on structural movement of areas of distress in the roof of the museum, in Battery Huger and in the Third System brick masonry pentagon.

Most importantly, it would, in installed in appropriate locations, measure movements due to a number of causes, including specifically:

- Foundation settlement,
- Unresisted thrust in the vaults,
- Rising sea level and
- Increased wave action due to larger ships.

Following these recommendations will provide valuable information about the past and ongoing structural movement of the fort that would be very difficult to obtain by other methods.

In order to better understand the structural behavior of Fort Sumter, we recommend that cracks and other signs of structural distress be regularly evaluated (see recommendations on installation of monitors above) and any changes to the masonry examined for indications of new structural distress. Combined with the laser scan, this evaluation will provide the information required for additional structural modeling and analysis. We recommend the development of three planar models: a section perpendicular to the rampart, a section parallel to the scarp wall, and a third section through the filled area along the right flank. These planar models would illustrate how individual structural systems of the fort act independently from one another. This information could then be applied to comprehensive analyses of interactions of the several elements.

Using information from the laser scan, conditions assessment, and planar models, a three dimensional structural model should be generated under the direction of Registered Professional Engineers who are legally able to do such work and have both the qualifications and the experience to make recommendations on the fort. Such a model has the potential to generate a more complete picture of structural stresses. We recommend that the model be focused on the right face, where we believe we could attain the best and most applicable results. In order to sufficiently show the acting forces, this model should include the salient, half of the left face, right face, and half of the right flank. The physical properties modeled and the displacements imposed in any model should be more consistent with the reality of the measured movements and observed behavior of the fort than the current model reflects. The three dimensional modeling is significant because it would pull together all of the separate elements and studies. This would in turn allow the structural engineer to determine whether or not intervention is appropriate and, if it is, where and what is necessary to prevent further damage to or loss of historic material.

Each of the recommended studies discussed above would contribute valuable information about Fort Sumter's structural behavior and integrity. Completing these studies is a necessary step in determining proper treatments and repairs for this National Monument.

**Endicott Era Battery Huger**

Recommendations for treatment of the Endicott era battery are particularly difficult. While concrete around corroding embedded steel can be removed, the steel treated with rust inhibitive coatings or replaced, and the concrete repoured, in reality all of the embedded steel will eventually require

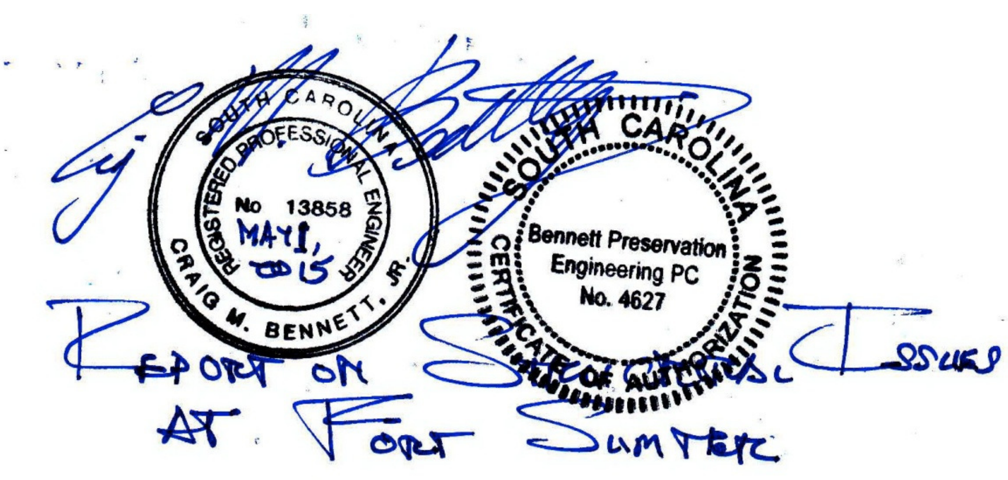
treatment or replacement. Considering that the Endicott battery has had a far less important role in the history of Fort Sumter than the Third System brick masonry pentagon, the presence of the Endicott battery makes comprehension of the Civil War era geometry of the fort difficult for visitors. Finally, considering the distinct possibility that the Endicott battery and the associated earth fill is doing significant damage to the east flank of the pentagon, we have to recommend that continued maintenance of the Endicott battery be questioned and that its removal be at the least, studied and considered. Even if the battery itself is not removed, the removal of the earth fill east of the battery absolutely must be carefully studied and, if no adverse effects found, acted upon.

We understand that the recommendations submitted in this report could require additional explanation and we welcome the opportunity to review our findings, conclusions and recommendations or to answer any questions.

We have based this report on information available to us at this time, but we also understand that conditions can change as additional information is uncovered. When such additional information becomes available, we would like to have the opportunity to reevaluate our conclusions.

This report was prepared by Craig M. Bennett, Jr., PE with help from F. Lyles McBratney, architectural conservator, Emma G. Kousouris and Taylor C. Frost, preservationists, and George H. Fischer, PE SE all of Bennett Preservation Engineering PC. It has additionally been reviewed by Bennett, McBratney, Kousouris and Joseph K. Oppermann, AIA.

We appreciate the opportunity to present this report to the National Park Service. We look forward to being of continuing service.




Craig M. Bennett, Jr., PE
Bennett Preservation Engineering PC

Figure 1:  Aerial photograph of Fort Sumter

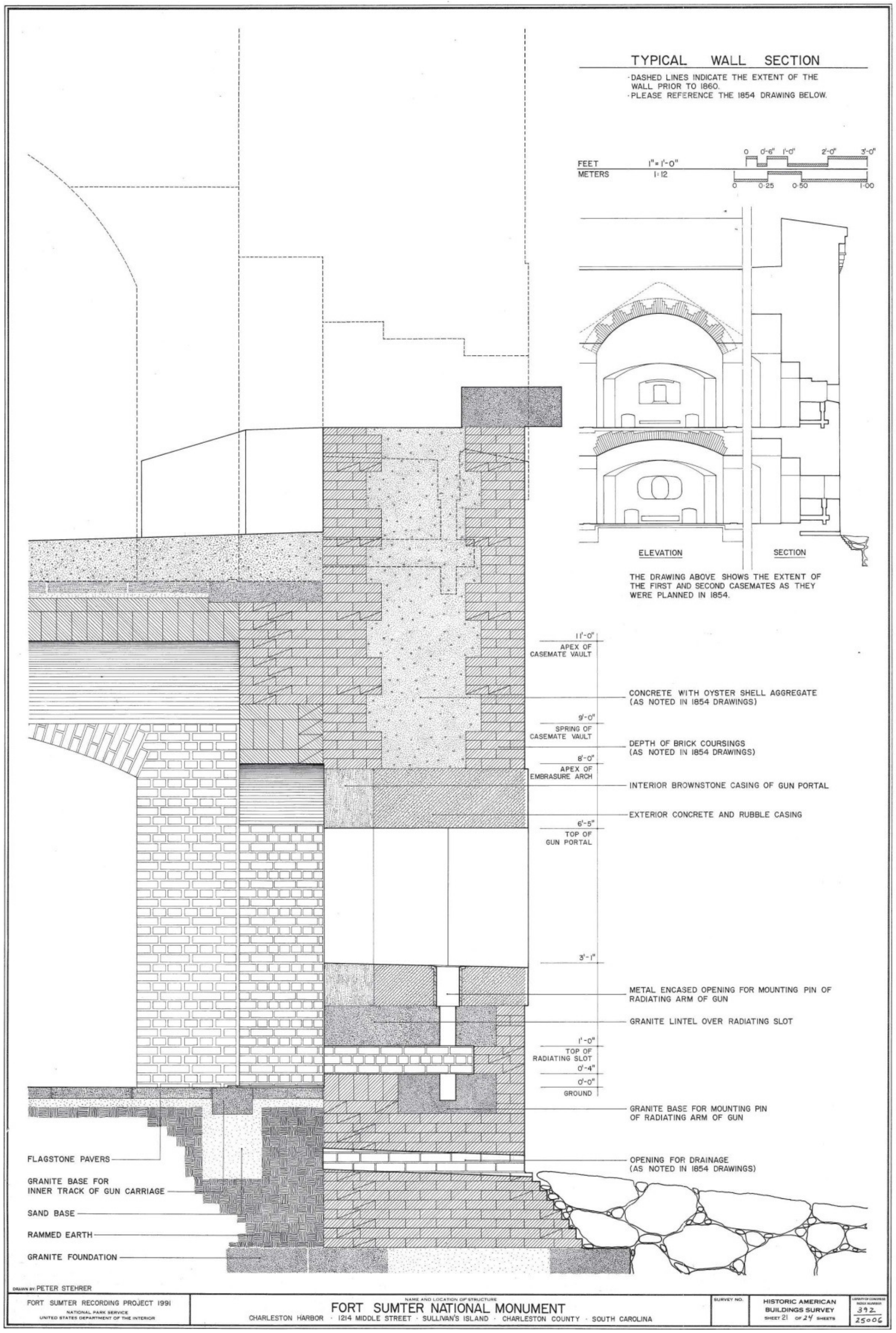



Figure 2: Fort Sumter Recording Project, HABS, 1991

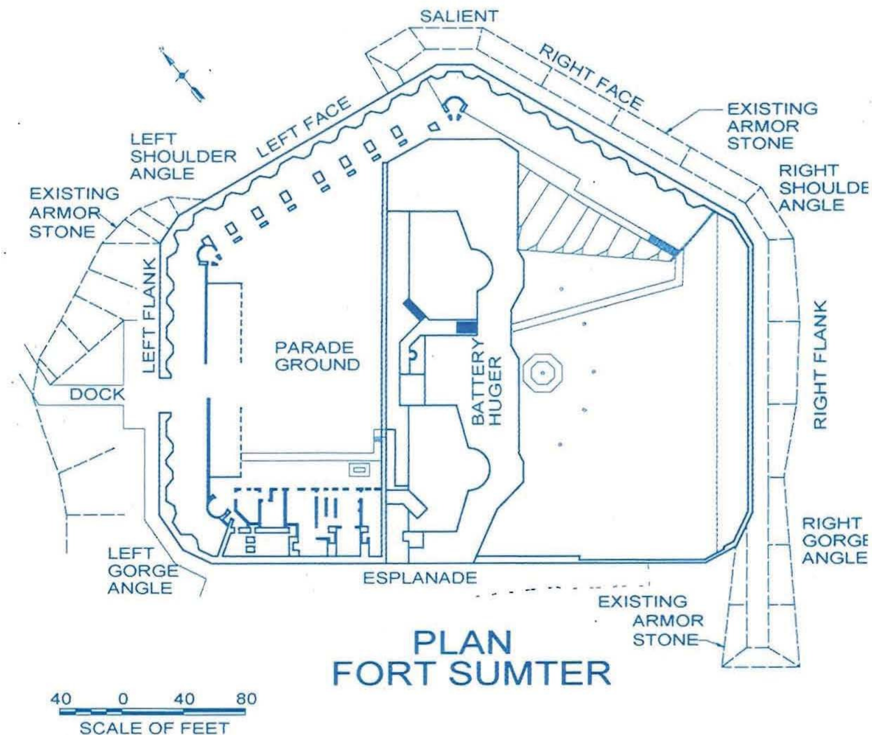



Figure 3: Plan of Fort Sumter, Armor Stone and Outer Wall Structural Study, 1998

Figure 4: Erosion of mortar below high water mark, Left Face, March 2009


Figure 5: Accelerated erosion around granite blocks, Right Face, March 2009


Figure 6: Erosion of wall surface, Right Face, March 2009

Figure 7: Erosion of wall surface and mortar, Right Face, March 2009

Figure 8: Portland cement used for repointing, Right Flank, March 2009

Figure 9:  Loose section of parapet/cornice, Left Flank, March 2009

Figure 10:  Bowing, Left Flank, March 2009


Figure 11:  Bowing, Gorge Wall, March 2009


Figure 12:  Right Flank, March 2009

Figure 13:  Bowing, Left Face, March 2009

Figure 14:  Masonry cracks, Right Face at Salient, March 2009


Figure 15:  Masonry crack, Right Flank, March 2009


Figure 16:  Masonry crack, Right Flank at Right Gorge, March 2009

Figure 17:  Masonry crack, Right Flank, March 2009

Figure 18:  Masonry crack, Gorge Wall and Right Gorge, March 2009

Figure 19:  Masonry crack, Right Gorge and Right Face, March 2009

Figure 20:  Cracks through arch, Right Face arcade, March 2009

Figure 21:  Cracks through arch, Right Face arcade, March 2009

Figure 22:  Crack running through vault and supporting arch, Right Face, March 2009

Figure 23:  Crack extending through vaults and supporting arches, Right Face, March 2009

Figure 24:  Several cracks are visible on this supporting arch at the Salient, March 2009

Figure 25: The crack in this vault has been repaired with epoxy, Left Flank, March 2009

Figure 26: The crack in this vault has been covered with concrete, but that patch has also cracked, Left Shoulder, March 2009

Figure 27:  This vault has cracked in both directions, Right Face, March 2009

Figure 28:  Cracks caused by internal pipe, Right Face, March 2009

Figure 29: Crack through corner of arch, Right Face, March 2009

Figure 30: Loose bricks inside fort, Left Face, March 2009


Figure 31: Cistern, March 2009


Figure 32: Original and rebuilt sections of the Right Gorge, March 2009


Figure 33: Original and rebuilt sections of the Right Gorge and Esplanade, March 2009


Figure 34: West wall of Battery Huger, December 2013

Figure 35: West wall of Battery Huger, December 2013

Figure 36: Structural fractures in West wall of Battery Huger, December 2013


Figure 37: Structural fractures in West wall of Battery Huger, December 2013


Figure 38: Structural fractures in West wall of Battery Huger, December 2013

Figure 39: Structural fractures in West wall of Battery Huger, December 2013

Figure 40: West Wall of Battery Huger, December 2013

Figure 41:  Structural fractures in West wall of Battery Huger, December 2013

Figure 42:  Corroding steel in joist system, December 2013

Figure 43:  Corroding steel in joist system, December 2013

Figure 44:  Corroding steel in joist system, December 2013

Figure 45: Corroding steel in joist system, December 2013

Figure 46: Corroding steel and jacking of concrete, December 2013


Figure 47:  Corroding steel and jacking of concrete, December 2013


Figure 48:  Corroding steel, December 2013

Figure 49:  Corroding steel, December 2013

Figure 50:  Corroding steel and jacking of concrete, December 2013

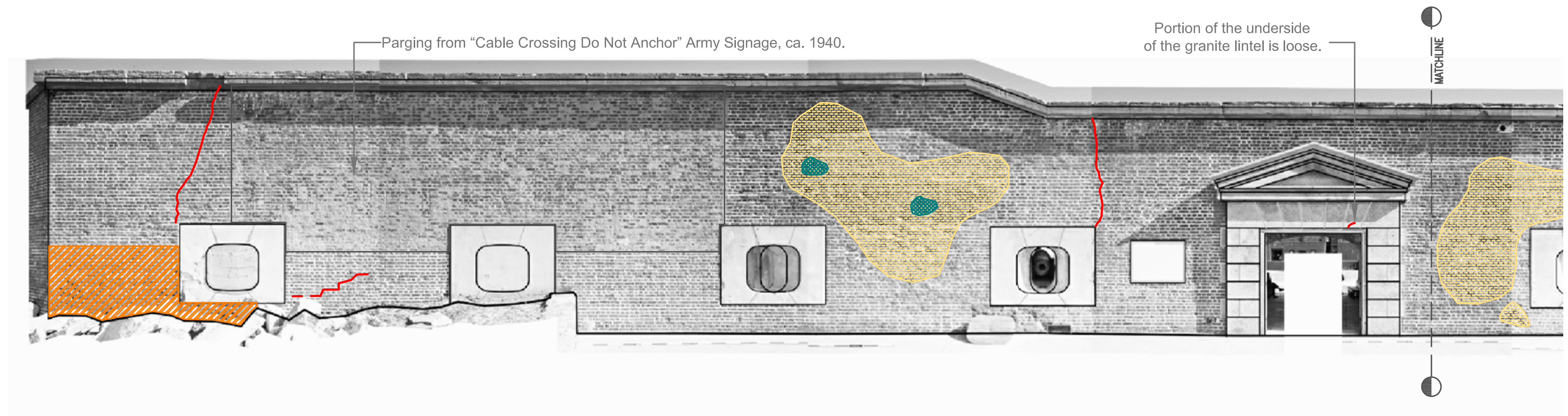
Figure 51: Observation Post, December 2013

Figure 52: Corrosion of the steel at the Observation Post, December 2013

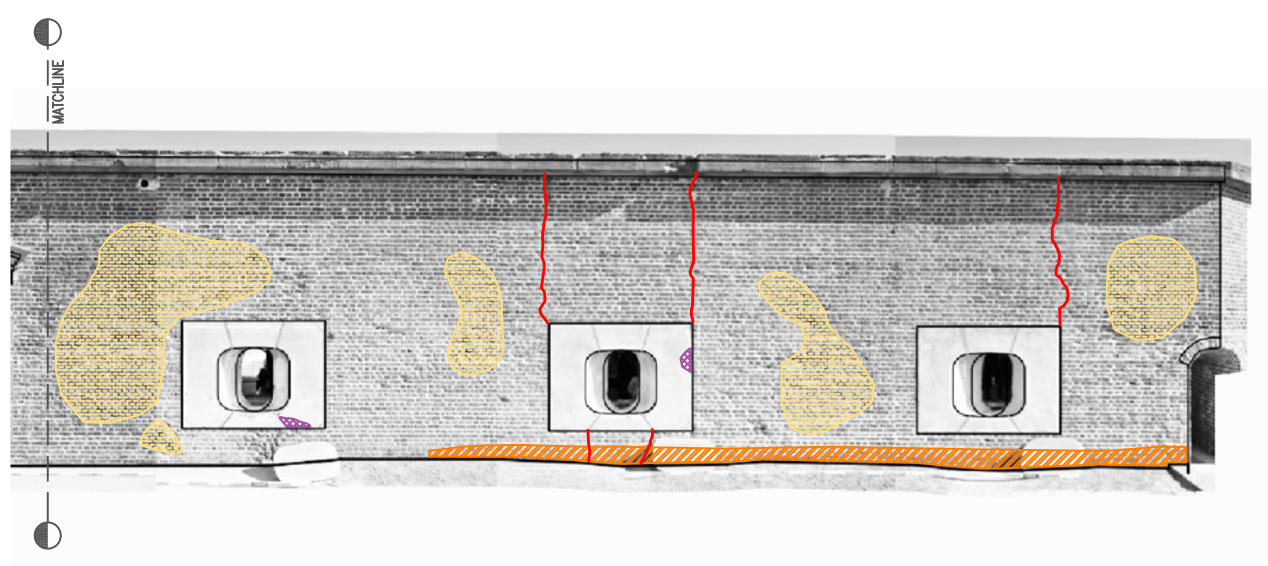
Figure 53: Structural fracture in the 2-way pan joist system of the museum ceiling, December 2013

# Appendix D: Exterior Elevation Conditions Drawings

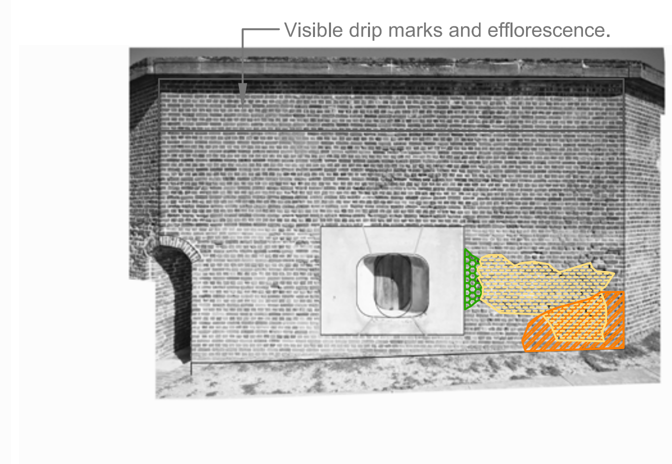
The following appendix includes a graphic conditions survey of the exterior elevations of Fort Sumter. Ortho-rectified photographs were taken by Peter Aaslestad of Aaslestad Preservation Consulting, LLC, in March 2013 to document the masonry walls that comprise the exterior and interior elevations. These photographs were measured and scaled, much the way an architectural drawing is prepared, to accurately depict both the dimensions and conditions of the existing walls. In December 2013, Building Conservation Associates, Inc. completed a cursory visual conditions survey of the exterior elevations using Aaslestad's ortho-rectified photographs. Conditions were recorded in the field using an HP Touchpad. Recorded conditions included significantly eroded or deteriorated walls surfaces, cracks, open mortar joints and areas of historic impact damage. Graphic representations or symbols of these conditions were overlaid on top of the photographs using AutoCAD. The annotated elevations are included in the following appendix in order to provide a general understanding of the masonry conditions and the level of integrity of the exterior walls, as well as an understanding of the most serious conditions at the time of the survey. Aaslestad's photographs and drawings could continue to be used for more in-depth conditions assessments, as well as future documentation of maintenance and conservation efforts at the fort.



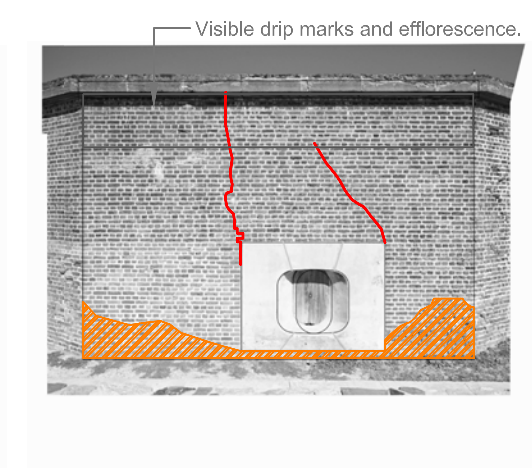

1 LEFT FLANK, NORTH END




2 LEFT FLANK, SOUTH END

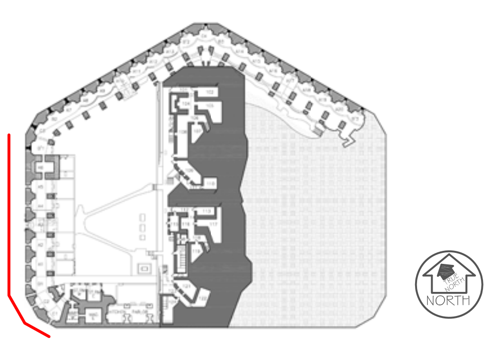



3 LEFT GORGE ANGLE, WEST




4 LEFT GORGE ANGLE, EAST

**SITE LOCATION**




**LEGEND**

- Deteriorated stucco surface
- Deteriorated brick surface
- Open mortar joints
- Historic impact damage
- Depression in brick surface
- Crack


BUILDING CONSERVATION ASSOCIATES INC
PHILADELPHIA, PENNSYLVANIA

# FORT SUMTER

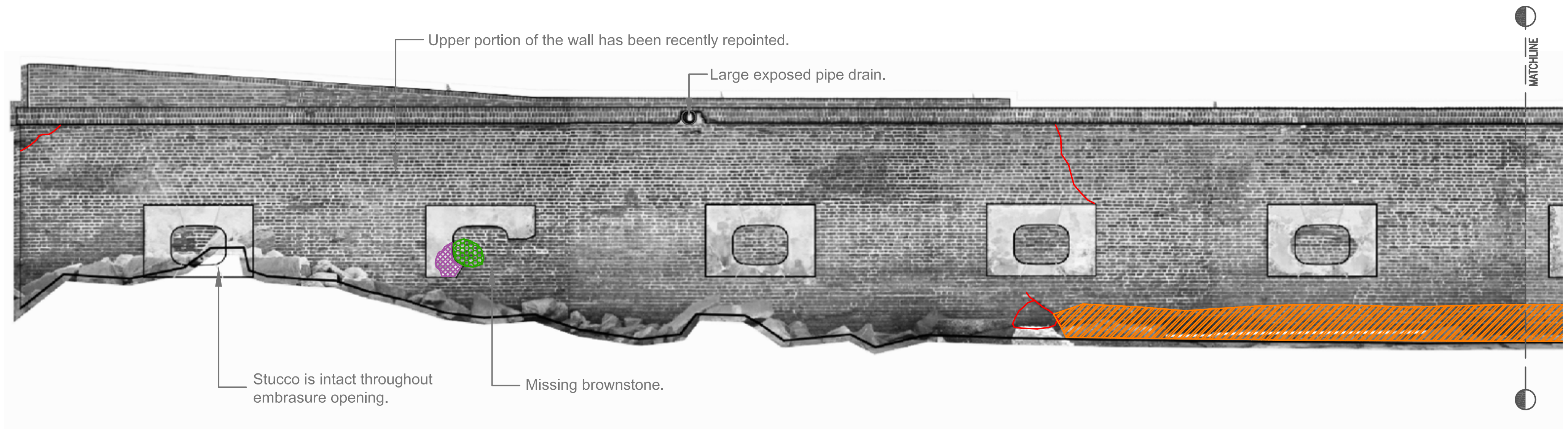
CHARLESTON HARBOR, SOUTH CAROLINA
U. S. DEPARTMENT OF THE INTERIOR - NATIONAL PARK SERVICE

PHOTOGRAPHY BY:
P. AASLESTAD
MARCH, 2013

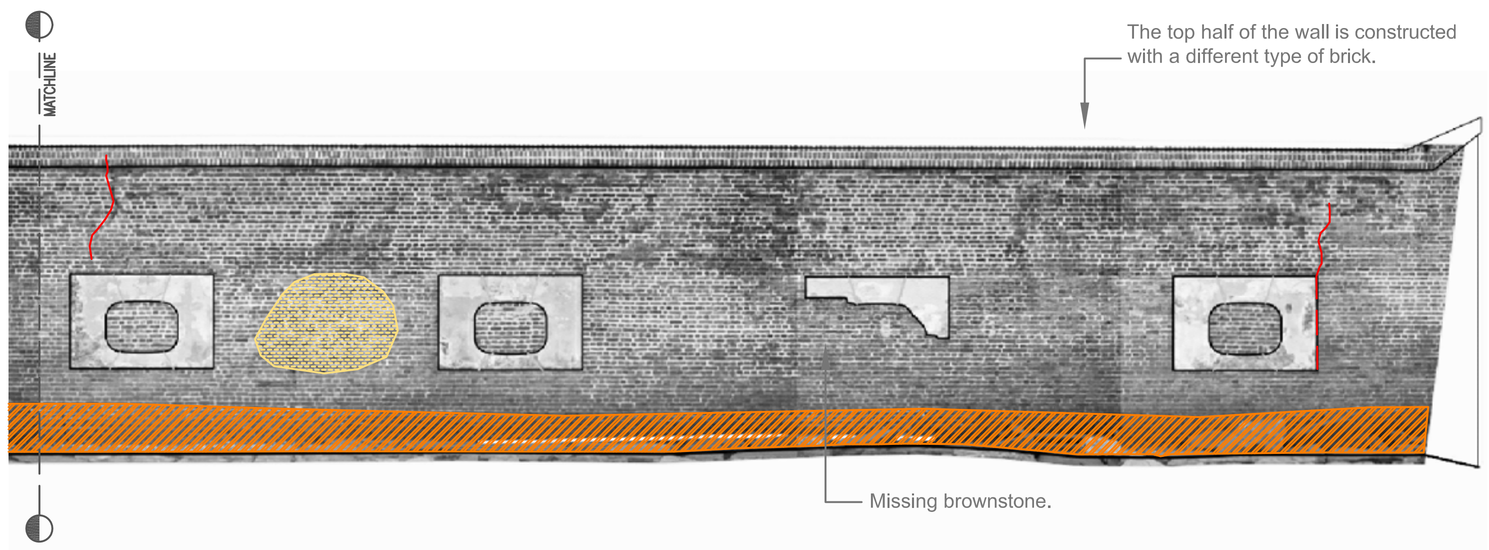
RECORDED BY:
L. DRAPALA
D. KROTZER
DECEMBER, 2013

DRAWING COMPLETED:
JULY, 2014

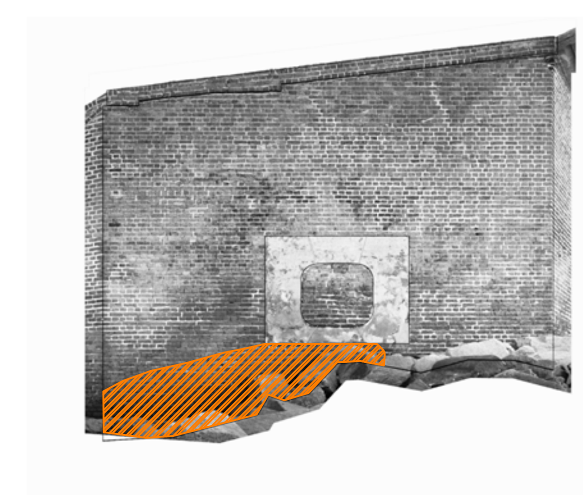
EXISTING CONDITIONS LEFT FLANK & LEFT GORGE ANGLE EXTERIOR ELEVATION




1 LEFT FACE, EAST END

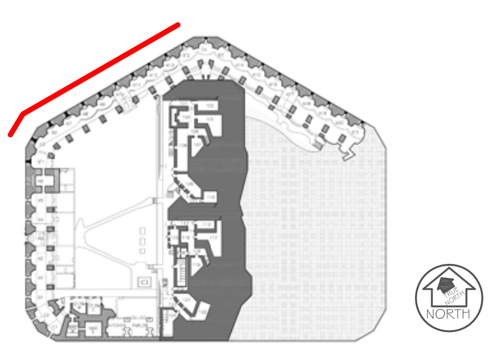



2 LEFT FACE, WEST END



3 LEFT SHOULDER ANGLE

**SITE LOCATION**




**LEGEND**

- Deteriorated stucco surface
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- Crack


BUILDING CONSERVATION ASSOCIATES INC
PHILADELPHIA, PENNSYLVANIA

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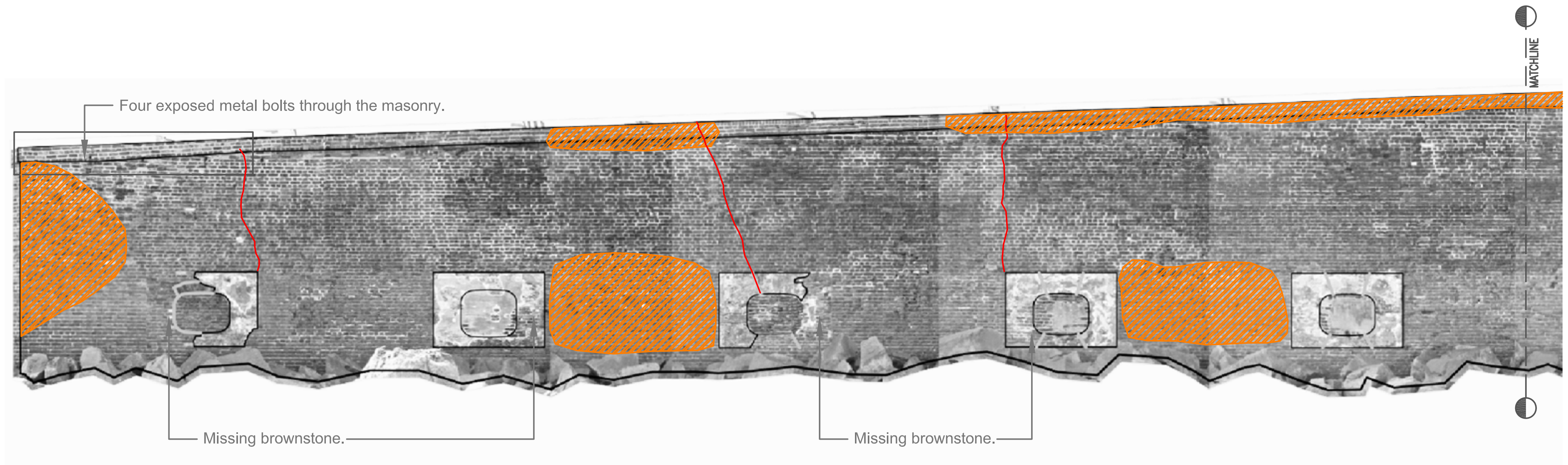
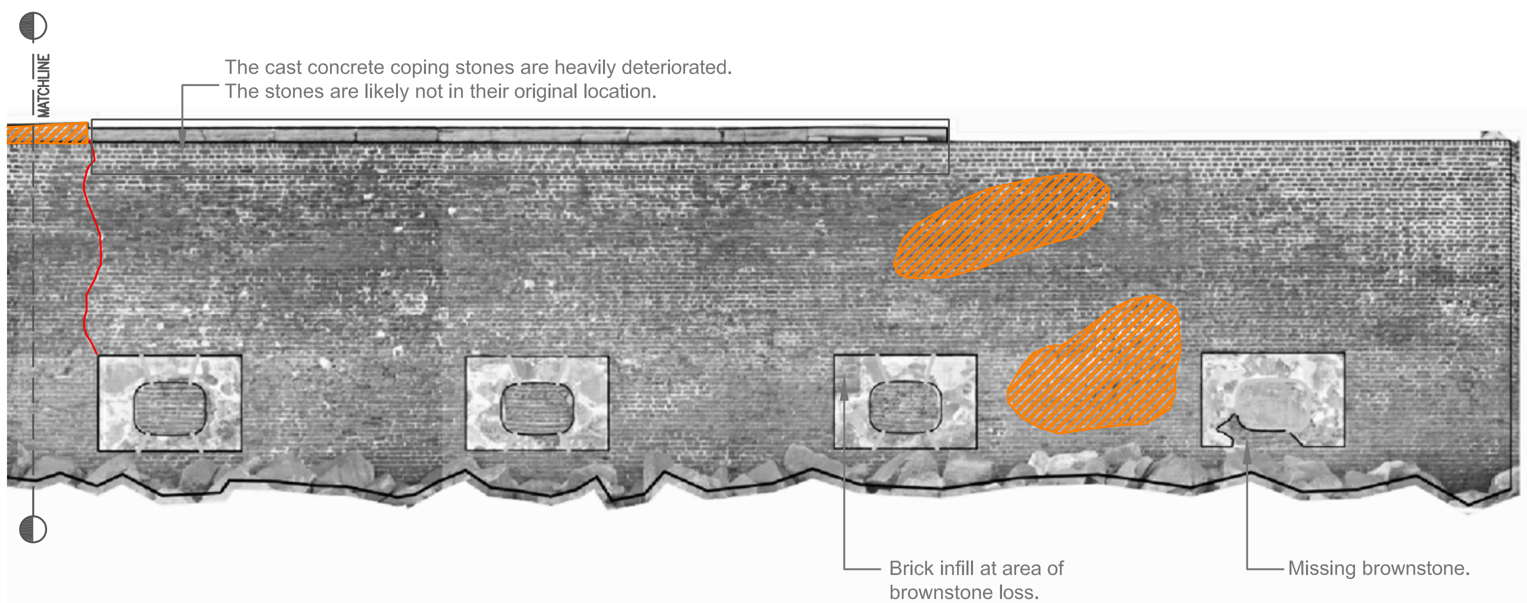
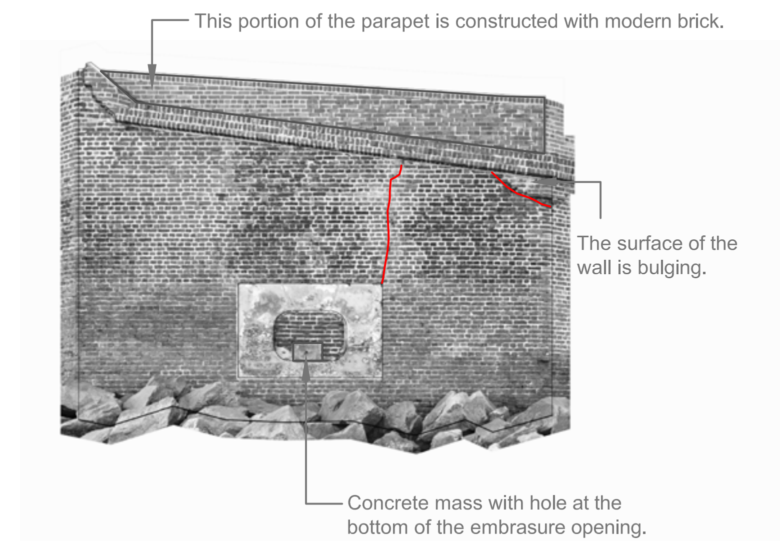
EXISTING CONDITIONS LEFT FACE & LEFT SHOULDER EXTERIOR ELEVATION




① RIGHT FACE, EAST END

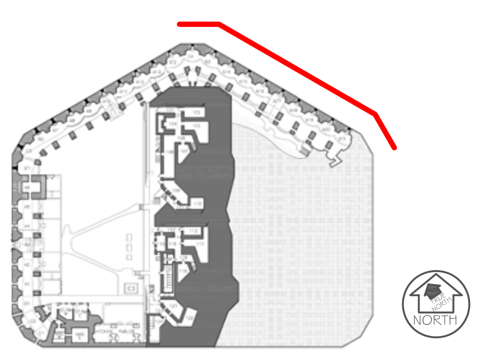



② RIGHT FACE, WEST END




③ SALIENT ANGLE

**SITE LOCATION**




**LEGEND**

- Deteriorated stucco surface
- Deteriorated brick surface
- Open mortar joints
- Historic impact damage
- Depression in brick surface
- Crack

0 10' 50'

BUILDING CONSERVATION ASSOCIATES INC
PHILADELPHIA, PENNSYLVANIA

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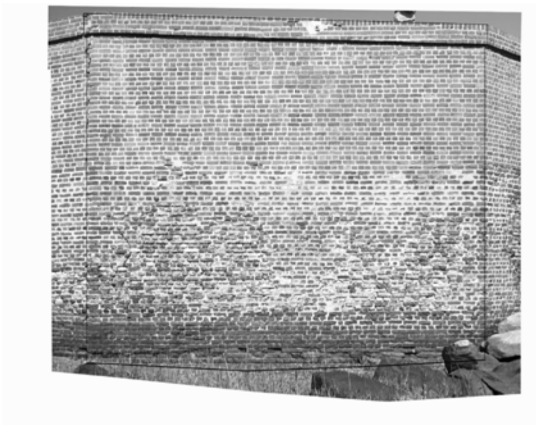
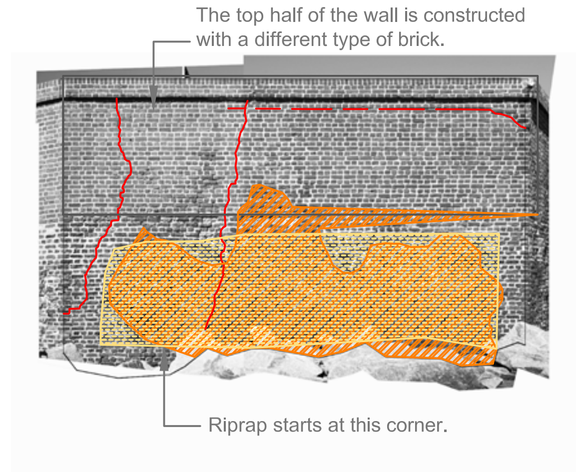
DECEMBER, 2013

DRAWING COMPLETED:
JULY, 2014

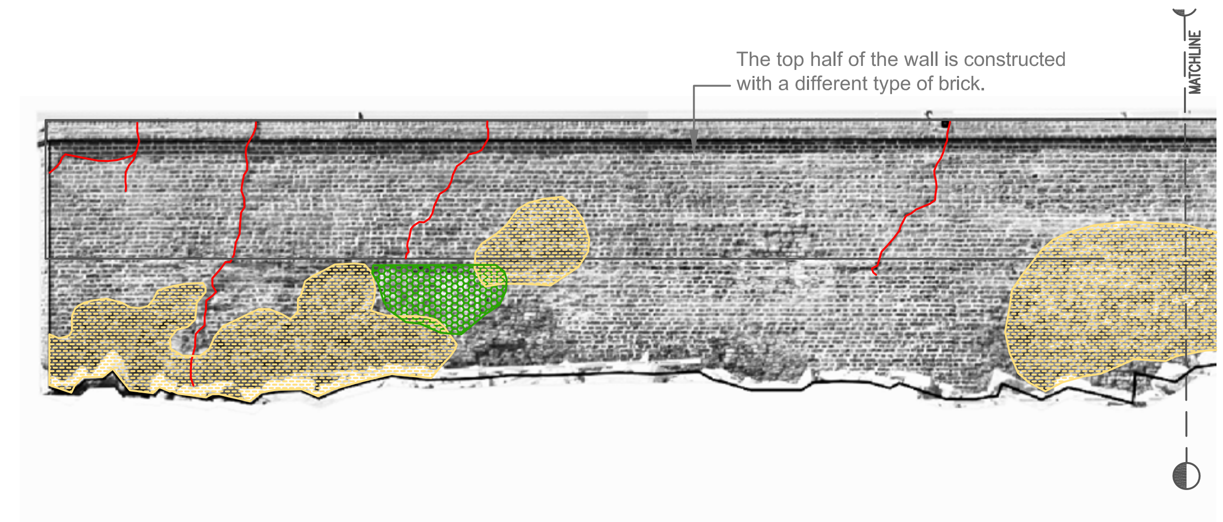
EXISTING CONDITIONS RIGHT FACE & SALIENT WALL EXTERIOR ELEVATION



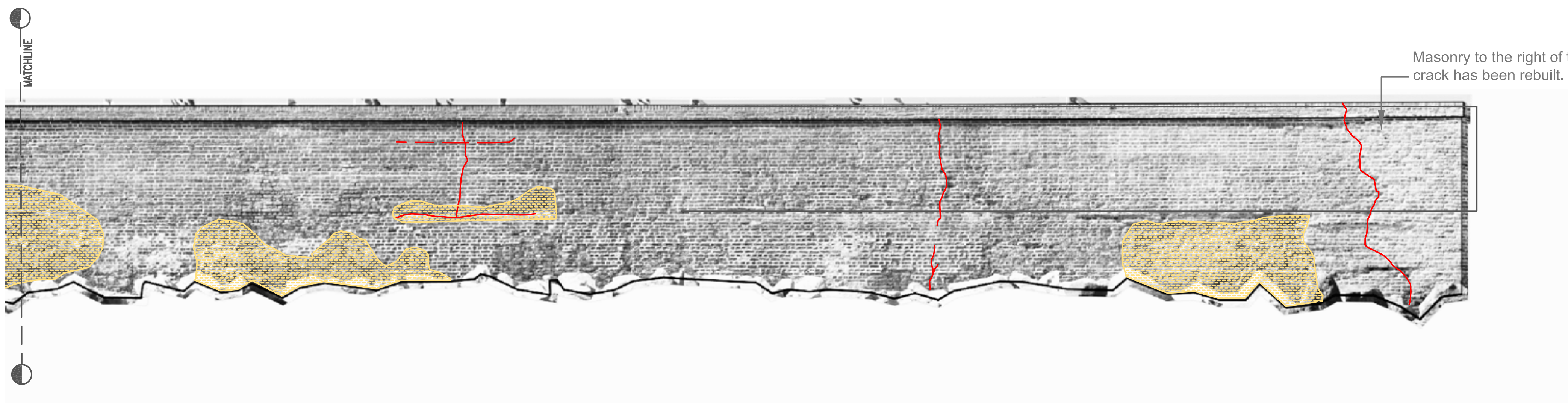
1 RIGHT GORGE ANGLE, WEST



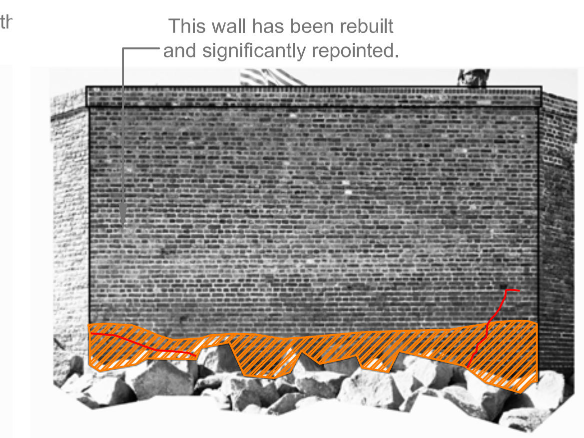

2 RIGHT GORGE ANGLE, EAST




3 RIGHT FLANK, SOUTH END

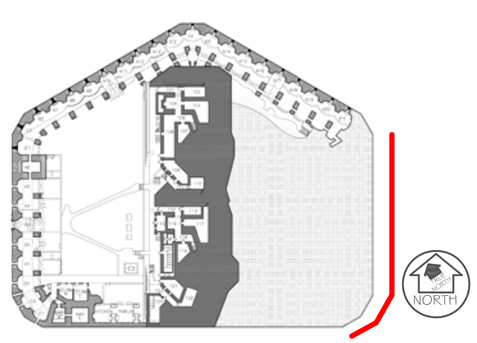



4 RIGHT FLANK, NORTH END




5 RIGHT SHOULDER ANGLE

**SITE LOCATION**




**LEGEND**

- Deteriorated stucco surface
- Deteriorated brick surface
- Open mortar joints
- Historic impact damage
- Depression in brick surface
- Crack


BUILDING CONSERVATION ASSOCIATES INC
PHILADELPHIA, PENNSYLVANIA

FORT SUMTER
CHARLESTON HARBOR, SOUTH CAROLINA
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MARCH, 2013

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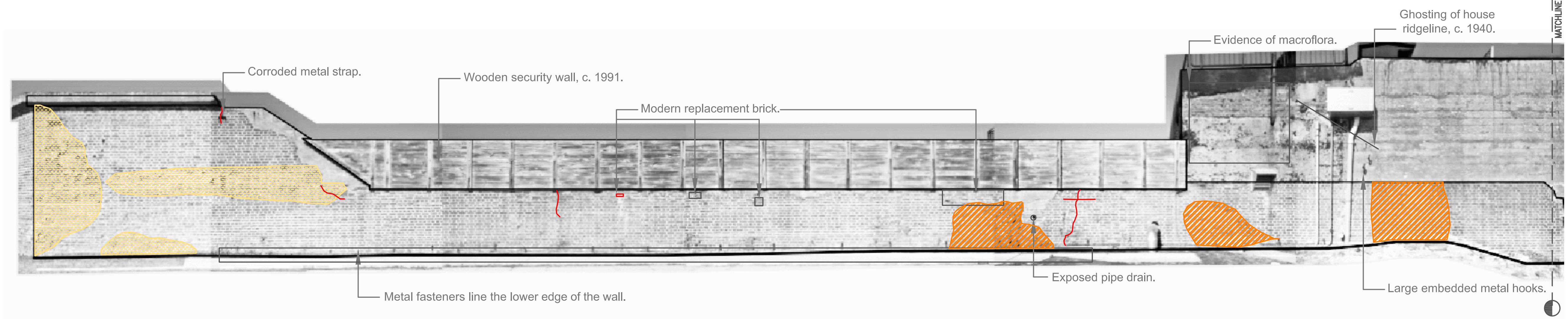
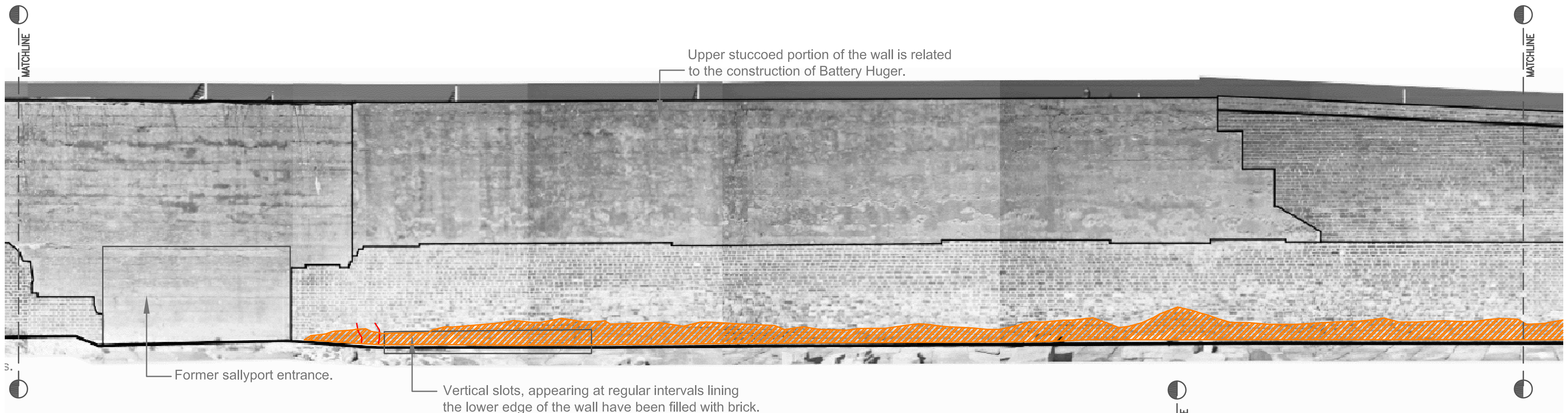
L. DRAPALA
D. KROTZER
DECEMBER, 2013

DRAWING COMPLETED:
JULY, 2014

EXISTING CONDITIONS RIGHT FLANK & GORGE ANGLE EXTERIOR ELEVATION



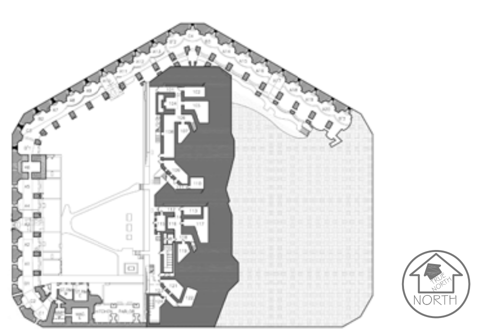

1 GORGE WALL, WEST END




2 GORGE WALL, CENTER


3 GORGE WALL, EAST END

**SITE LOCATION**




**LEGEND**

- Deteriorated stucco surface
- Deteriorated brick surface
- Open mortar joints
- Historic impact damage
- Depression in brick surface
- Crack

0 10' 50'

BUILDING CONSERVATION ASSOCIATES INC
PHILADELPHIA, PENNSYLVANIA

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CHARLESTON HARBOR, SOUTH CAROLINA
U. S. DEPARTMENT OF THE INTERIOR - NATIONAL PARK SERVICE

PHOTOGRAPHY BY:
P. AASLESTAD
MARCH, 2013

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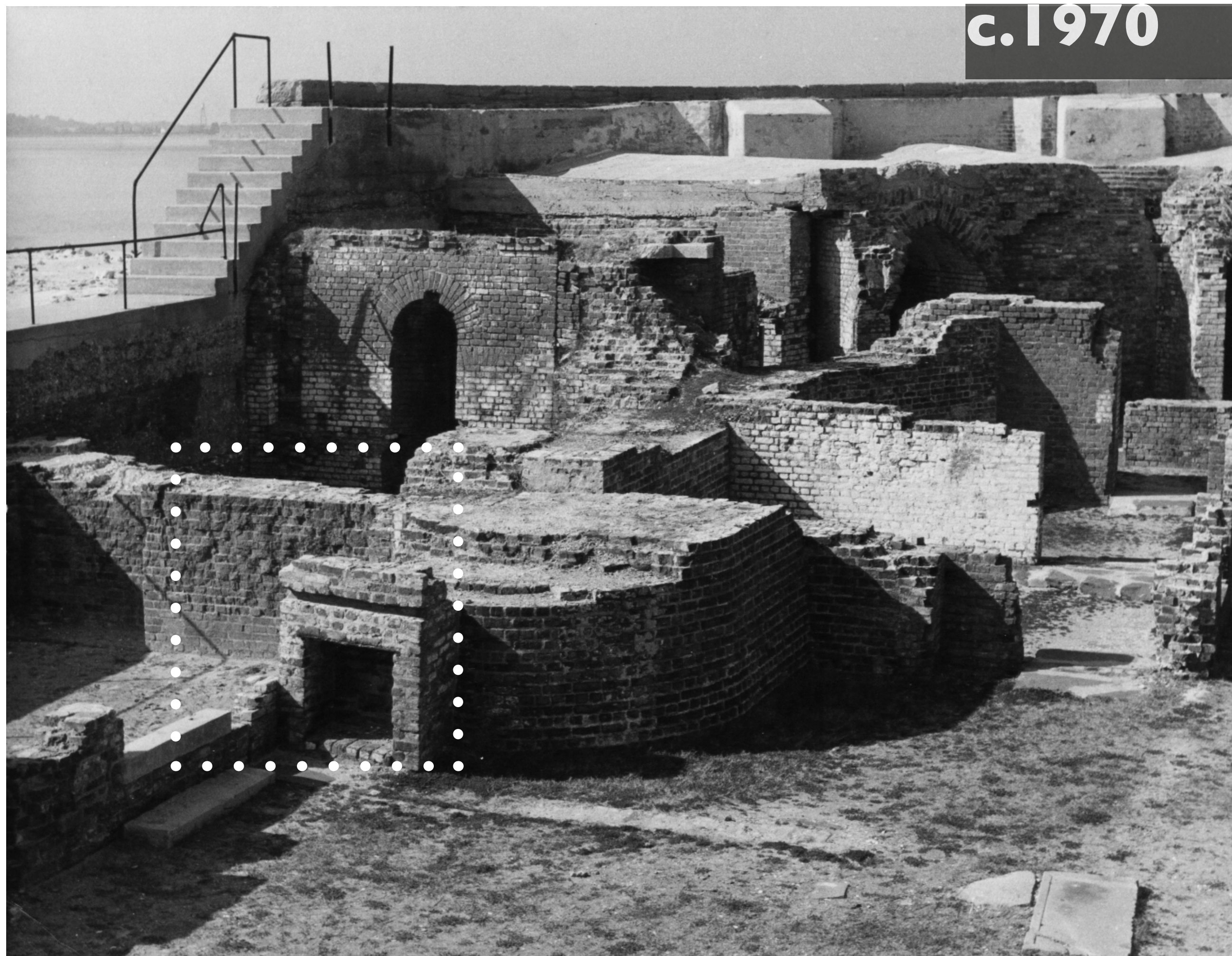
L. DRAPALA
D. KROTZER
DECEMBER, 2013

DRAWING COMPLETED:
JULY, 2014

EXISTING CONDITIONS GORGE WALL EXTERIOR ELEVATION

# Appendix E: Comparative Photos, Historic & Current

This appendix contains a series of historic images of Fort Sumter, juxtaposed with similar views taken in December 2013. Building Conservation Associates, Inc. compiled the historic images, ranging from ca. 1940 to 1991, and took comparable photographs with current views in December 2013. The intention of these photographic comparisons is to illustrate the rate of deterioration of materials throughout the fort, as well as alterations and interventions made over the past 75 years.





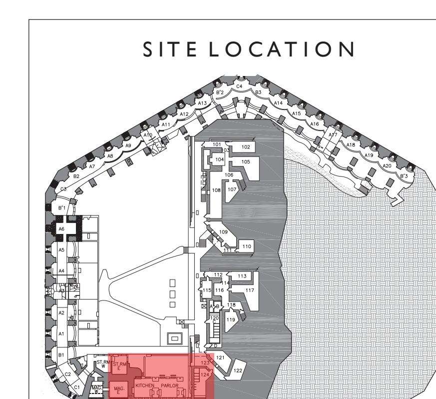
**LOCATION**

Gorge wall archeological ruins, looking west. [Credit: Fort Sumter Archives]

**OBSERVATIONS**

- The metal railing on the gorge wall that was present in c. 1970 was later replaced with the current wooden security wall.
- The traces of white finishes present in the c. 1970s are no longer extant.

**CONDITION DETAIL**





**LOCATION**

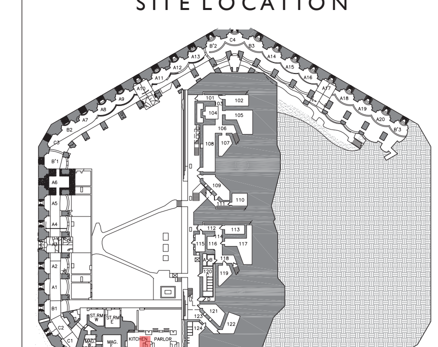
Gorge wall archeological ruins, herringbone brick hearth in the Kitchen area, looking east. [Credit: Fort Sumter Archives]

**OBSERVATIONS**

- The fireplace surround is no longer intact.

**CONDITION DETAIL**

SITE LOCATION





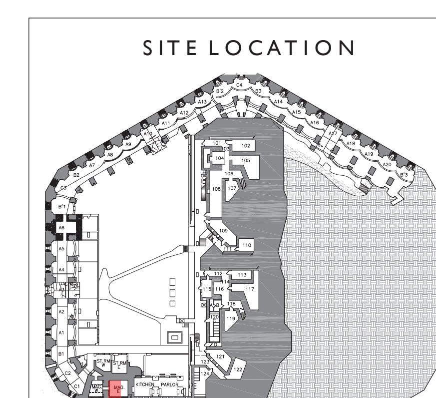
**LOCATION**

Gorge wall archeological ruins. The remains of Magazine East, looking west. [Credit: Jack Boucher]

**OBSERVATIONS**

- The horizontal cracking on the northside of the vaulted hallway into Magazine West appears to have been stabilized and filled with patching mortar.
- Many of the open mortar joints that were visible in 1963 have since been re-pointed.
- Brick has been infilled in the vertical spaces on the northern and southern-most portions of the wall.

**CONDITION DETAIL**





## LOCATION

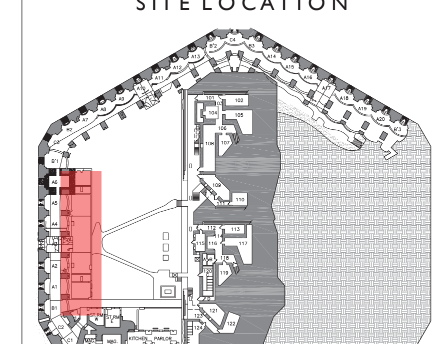
Left Flank Casemates, looking north from the Gorge Wall Archeological Ruins.
[Credit: Jack Boucher]

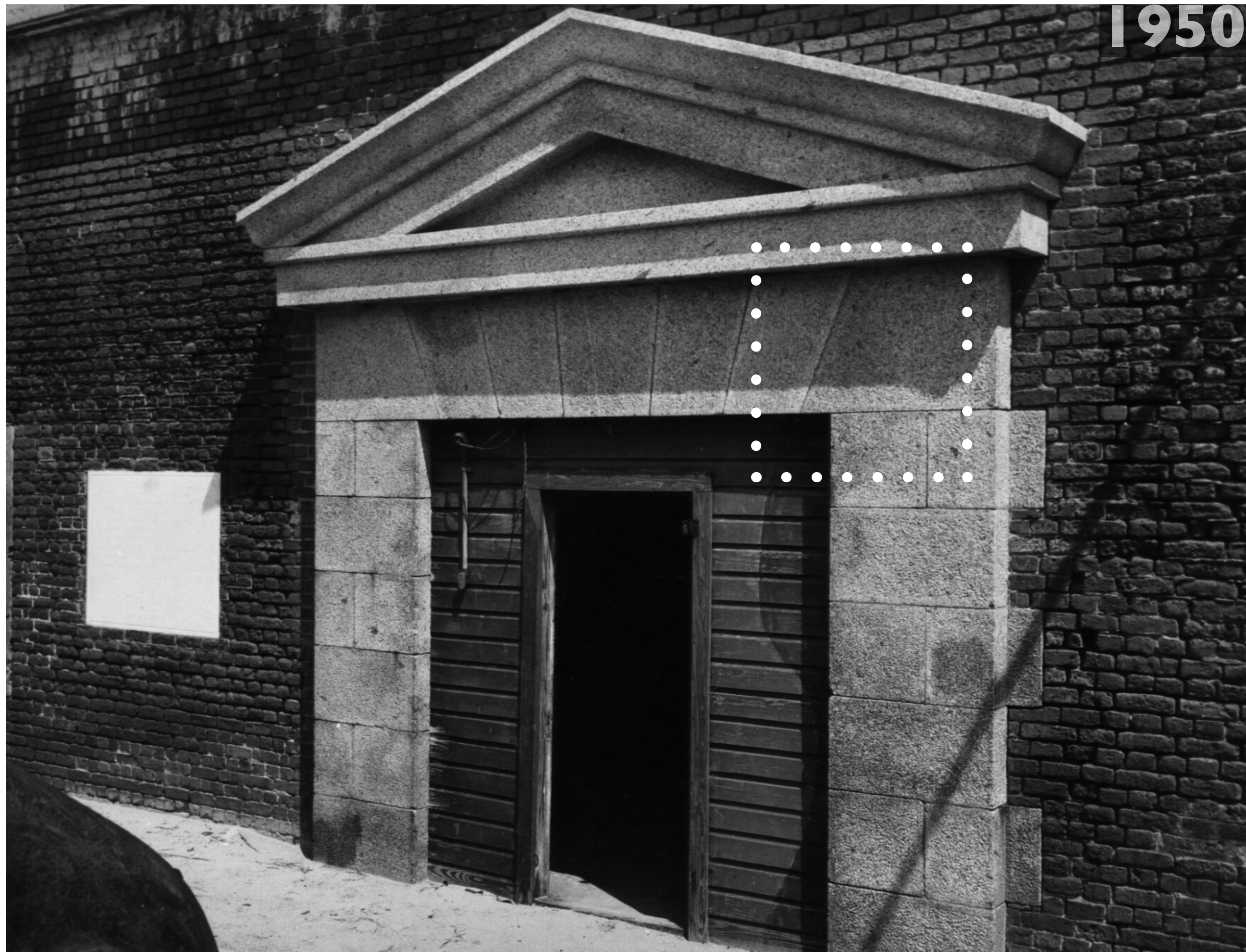
## OBSERVATIONS

- The flooring at the rear of the Left Flank Casemates has been repaved.
- There has been an overall loss of white finishes on the brick masonry since 1963.

CONDITION DETAIL

SITE LOCATION







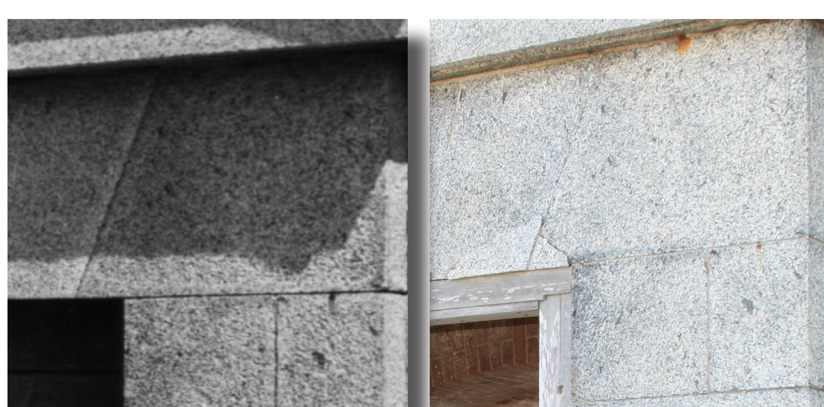
**LOCATION**

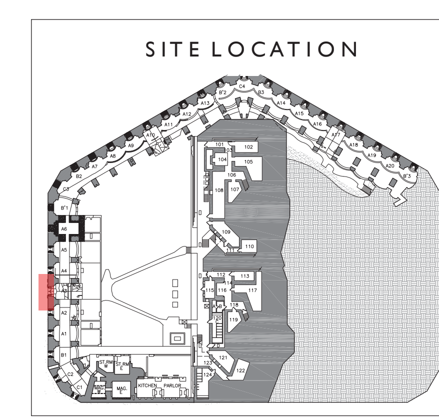
Left Flank Casemates, exterior Sallyport entrance. [Credit: Fort Sumter Archives]

**OBSERVATIONS**

- The single door entrance in 1950 was replaced with a two-door entrance that was meant to reproduce the appearance of the mid-nineteenth century sallyport door opening.
- A portion of the granite lintel (shown in the detail) has cracked and is about to spall.

**CONDITION DETAIL**







**LOCATION**

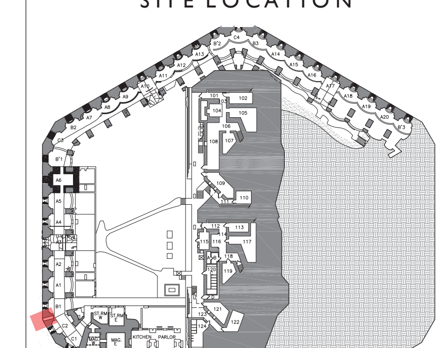
Left Flank Casemates, exterior southwest corner entrance. [Credit: Fort Sumter Archives]

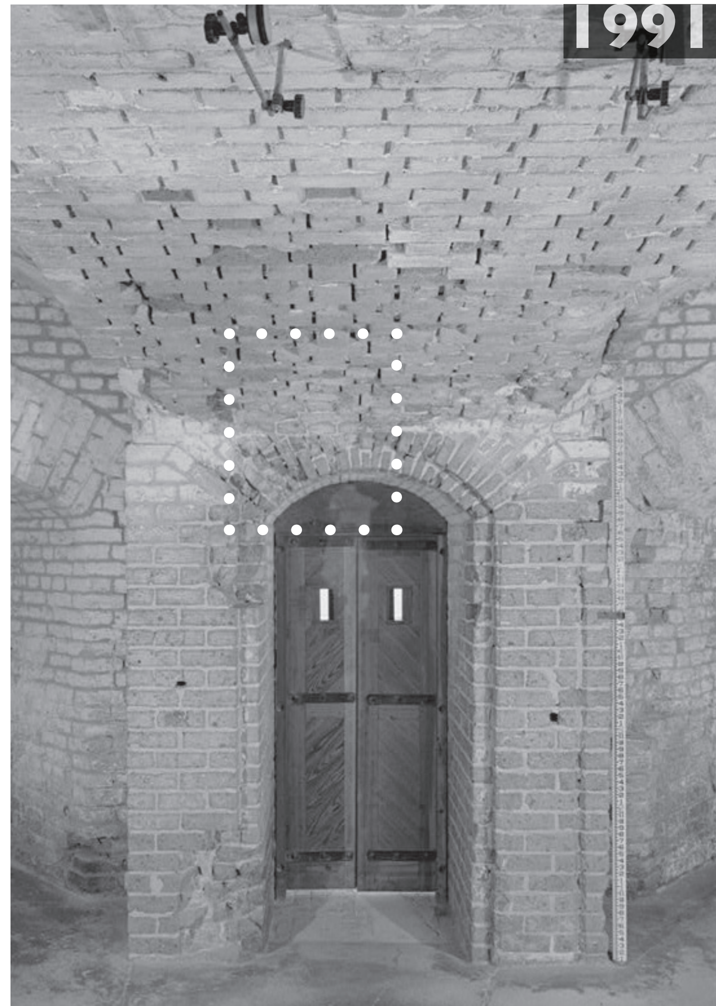
**OBSERVATIONS**

- The brick masonry surrounding this door opening has been replaced and repointed since 1948.

**CONDITION DETAIL**

SITE LOCATION







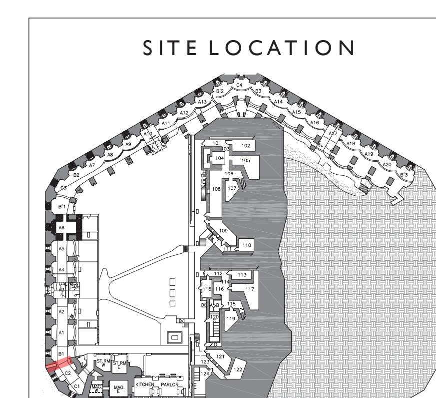
**LOCATION**

Left Flank Casemates, looking southwest from in the interior of the southwest corner door opening. [Credit: Historic American Buildings Survey]

**OBSERVATIONS**

- The brick surface appears to be consistent from 1991 to 2013.
- The door installation is also consistent.

**CONDITION DETAIL**





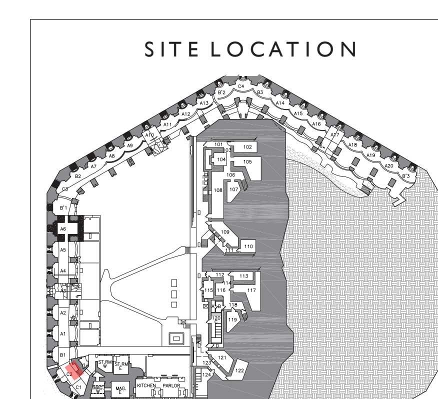
**LOCATION**

Left Flank Casemates, rear wall of Casemate C-2. [Credit: Historic American Buildings Survey]

**OBSERVATIONS**

- The cracks in the upper left and right corners present in 1991 appear to have been treated, as the cracks are no longer as prominent.

**CONDITION DETAIL**





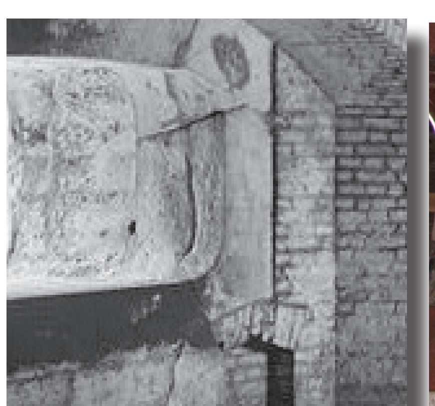
**LOCATION**

Left Flank Casemates, looking north with Casemate C2 in the forefront. [Credit: Jack Boucher]

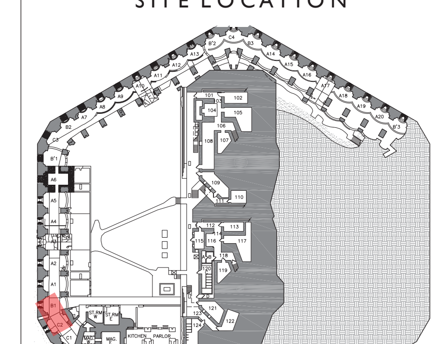
**OBSERVATIONS**

- Many of the white finishes are no longer intact on the brick and brownstone masonry.
- The crack through the granite lintel in Casemate C2 was visible in 1963, though it appears the crack has since spread into the brownstone.

**CONDITION DETAIL**



SITE LOCATION





**LOCATION**

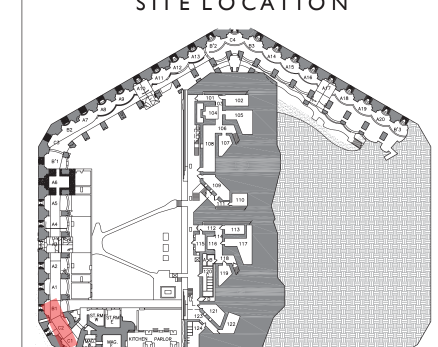
Left Flank Casmemates, from Casemate B-1 looking into Casemates C-2 and C-1. [Credit: Historic American Buildings Survey]

**OBSERVATIONS**

- The cracks in the ceiling have been treated since 1991, though the treatment repairs have since opened.
- Losses on the south corner of southwest corner doorway to the exterior have been filled with patching mortar.
- There has been loss of the white finishes on the brownstone embrasure.

**CONDITION DETAIL**

SITE LOCATION





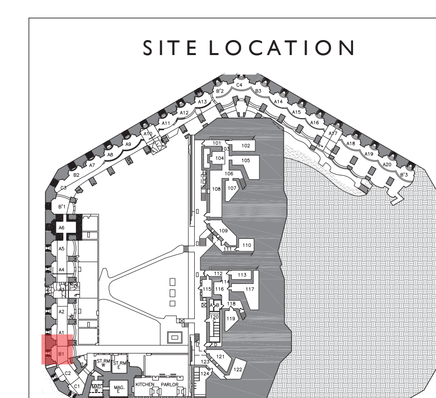
**LOCATION**

Left Flank Casemates, Casemate B1, c. 1940s [Credit: Fort Sumter Archives]

**OBSERVATIONS**

- There has been a loss of white finishes on the brick and brownstone masonry from the 1940s to 2013.

**CONDITION DETAIL**





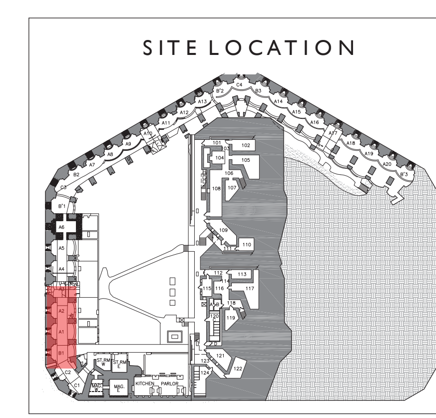
**LOCATION**

Left Flank Casemates, view from Casemate C2 looking north. [Credit: Fort Sumter Archives]

**OBSERVATIONS**

- There has been a loss of white finishes on the brick and brownstone masonry from the 1970s to 2013.
- The benches have been added since the 1970s.
- The temporary pedestal in Casemate B1 has been added for the park rangers, to add in the interpretation of the site.

**CONDITION DETAIL**





**LOCATION**

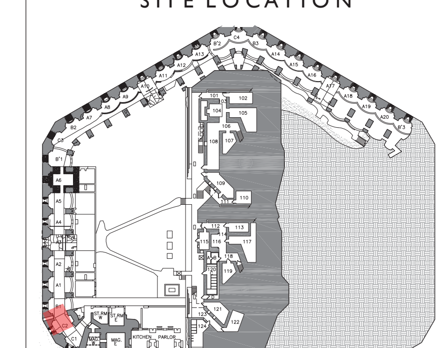
Left Flank Casemates, from Casemate C2 into Passage of B1, located in the Southwest Quadrant. [Credit: Historic American Buildings Survey]

**OBSERVATIONS**

- The brick loss on the underside of the separation arch appears consistent from 1991 to 2013, with continued erosion of the brick's surface.

**CONDITION DETAIL**

SITE LOCATION






**LOCATION**

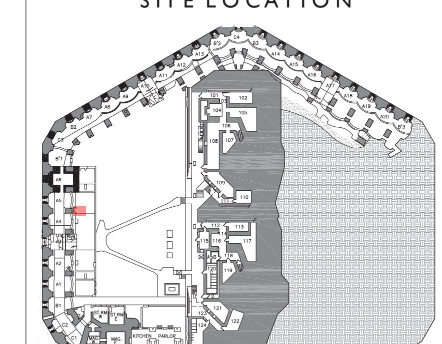
Left Flank Casemates, Left: The rear east wall of Casemate A5, in the Enlisted Men's Barracks [Credit: Fort Sumter] Middle: The fireplace installation at the rear parade ground pier between Casemates A4 and A5. [Credit: Jack Boucher]

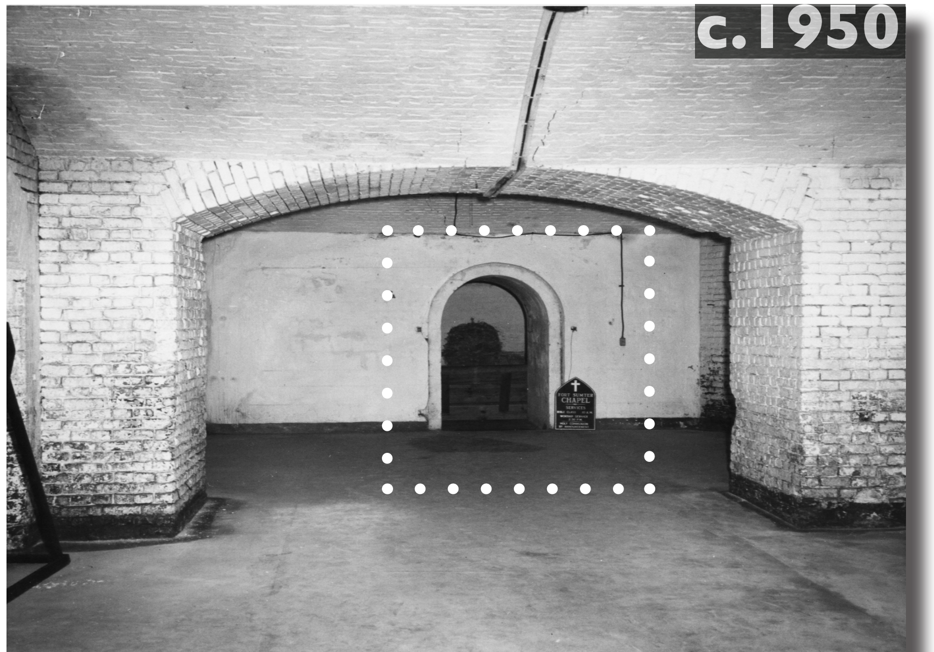
**OBSERVATIONS**

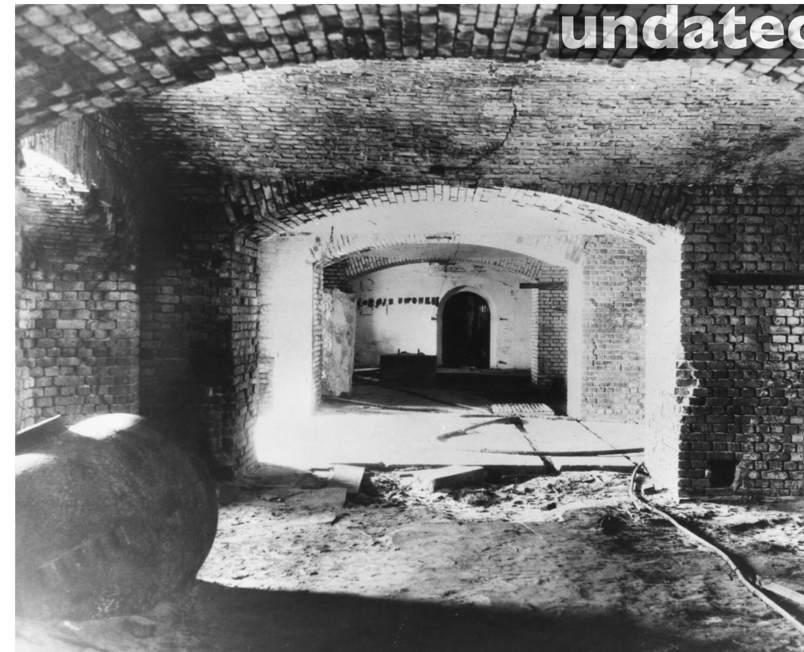
- The fireplace was originally installed in the rear wall of Casemate A5, when the area was used as the Enlisted Men's Barracks. When the wall was demolished, the fireplace was re-installed at the rear parade ground pier between Casemates A4 and A5.
- The fireplace and surrounding masonry has lost a significant amount of white finishes from 1963 to 2013.

**CONDITION DETAIL**

SITE LOCATION







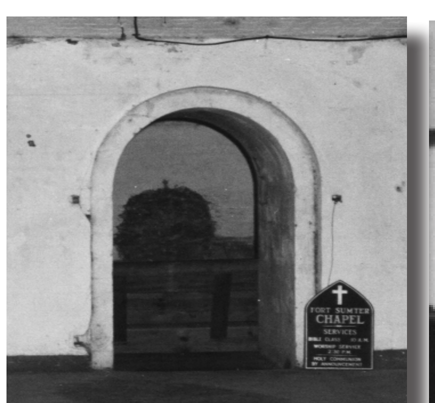
**LOCATION**

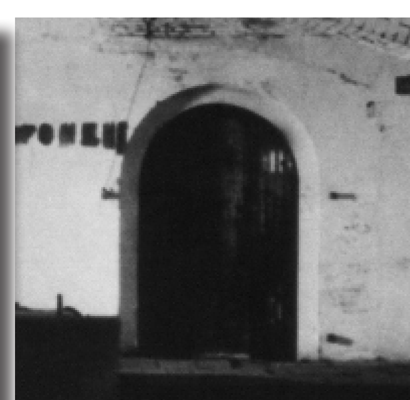
Left Flank Casemates, looking towards Mining Casemate (A6). [Credit: Fort Sumter Archives]

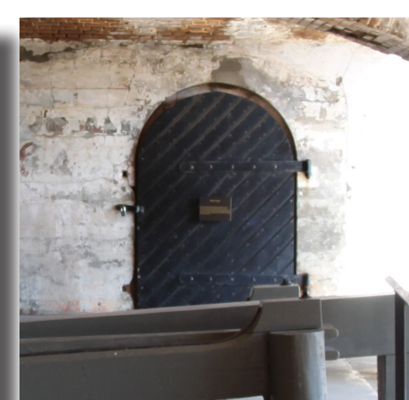
**OBSERVATIONS**

- A door was not installed on the opening to Casemate A6 in the left flank in c. 1950, and two different doors have been installed since that date.
- Fragments of the "undated" paint scheme are still intact on the north wall of Casemate A5, to the left of the door opening.
- The ceiling strip used for the installation of utilities in c. 1950 was later removed and replaced by an underground trench dug in Casemate A3, shown in the "undated" photo and currently visible as the vertical patch in the flooring of Casemate A3.

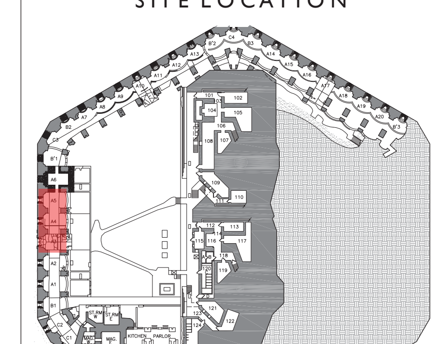
**CONDITION DETAIL**







SITE LOCATION





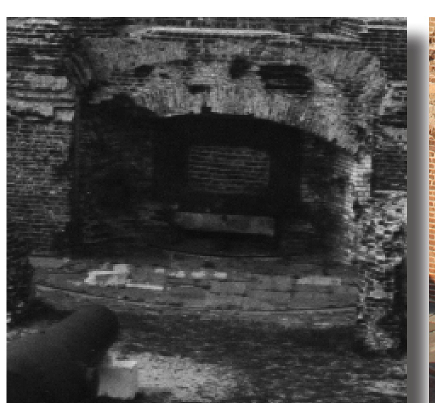
**LOCATION**

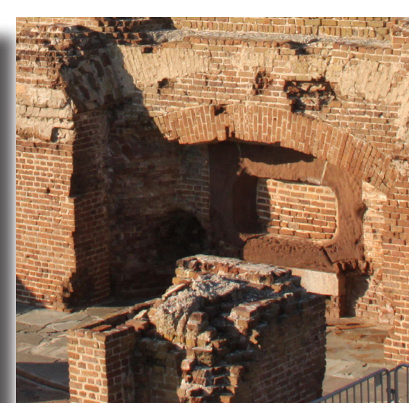
Left Face Casemates, with Casemate A10 (noted by its granite paving) visible at the far right. [Credit: Fort Sumter Archives]

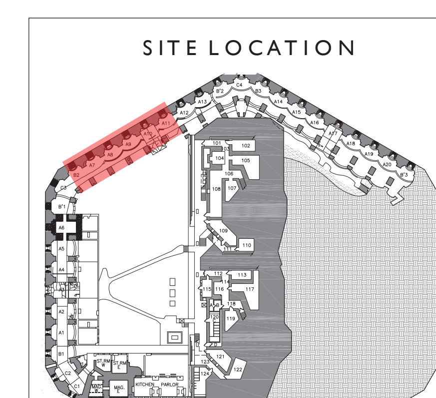
**OBSERVATIONS**

- The condition of the parade ground piers generally appears to be consistent from 1968 to 2013.
- The boat dock is in the same location as it was in 1968.

**CONDITION DETAIL**









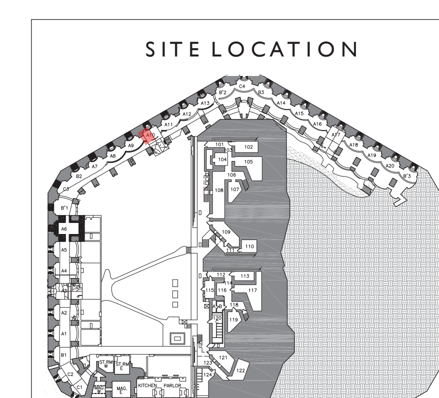
**LOCATION**

Left Face Casemates, western angled wall of Casemate A10. [Credit: Fort Sumter Archives]

**OBSERVATIONS**

- There has been a loss of white finishes on the brick and brownstone masonry from 1991 to 2013.
- The previously installed metal elements (in the lower right portion of the photograph from c. 1970) are no longer extant.

**CONDITION DETAIL**





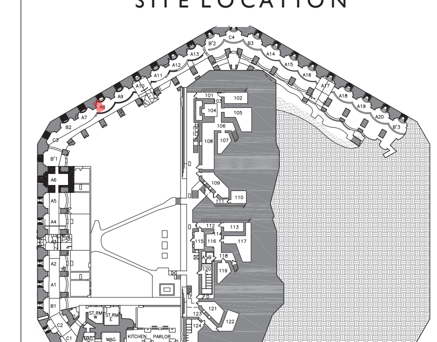
**LOCATION**

Left Face Casemates, Detail of shell casing in the west angled wall of Casemate A8. [Credit: Historic American Buildings Survey]

**OBSERVATIONS**

- The metal artifact appears to have further evidence of corrosion on its surface between 1991 and 2013.

SITE LOCATION





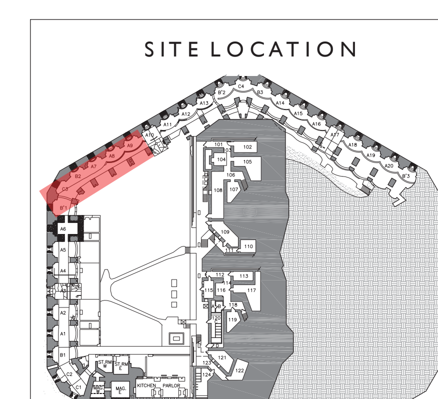
**LOCATION**

Left Face Casemates, looking down the corridor from Casemate A-9 through to C-3. [Credit: Historic American Buildings Survey]

**OBSERVATIONS**

- Many of the mortar joints have deteriorated significantly since 1991.

**CONDITION DETAIL**





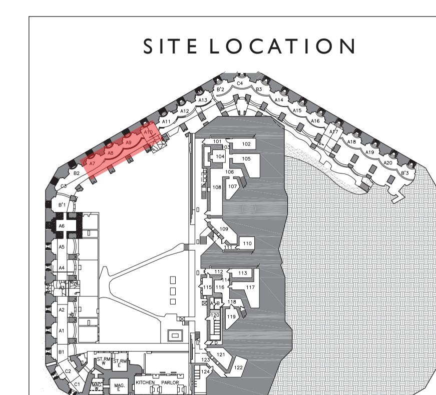
**LOCATION**

Left Face Casemates, looking towards the Salient Angle. [Credit: Jack Boucher]

**OBSERVATIONS**

- Many of the white finishes on the brick masonry and brownstone are no longer intact.
- The pavement appears consistent from 1963 to 1991.

**CONDITION DETAIL**





**LOCATION**

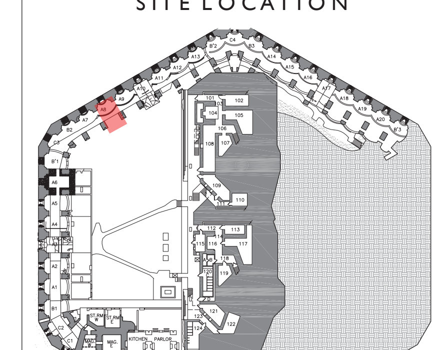
Left Face Casemates, the north wall of Casemate A8 [Credit: Jack Boucher]

**OBSERVATIONS**

- The inner canon traverse track has been removed since 1968.
- The surface of the brownstone has deteriorated significantly since 1968, fracturing in many places, with visible alveolar erosion throughout its surface.
- Many of the white finishes on the brick masonry and brownstone are no longer intact.

**CONDITION DETAIL**

SITE LOCATION





**LOCATION**

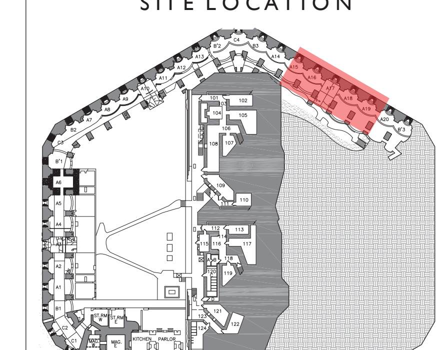
Right Face Casemates, Casemate A-18 in the forefront, looking north. [Credit: Historic American Buildings Survey]

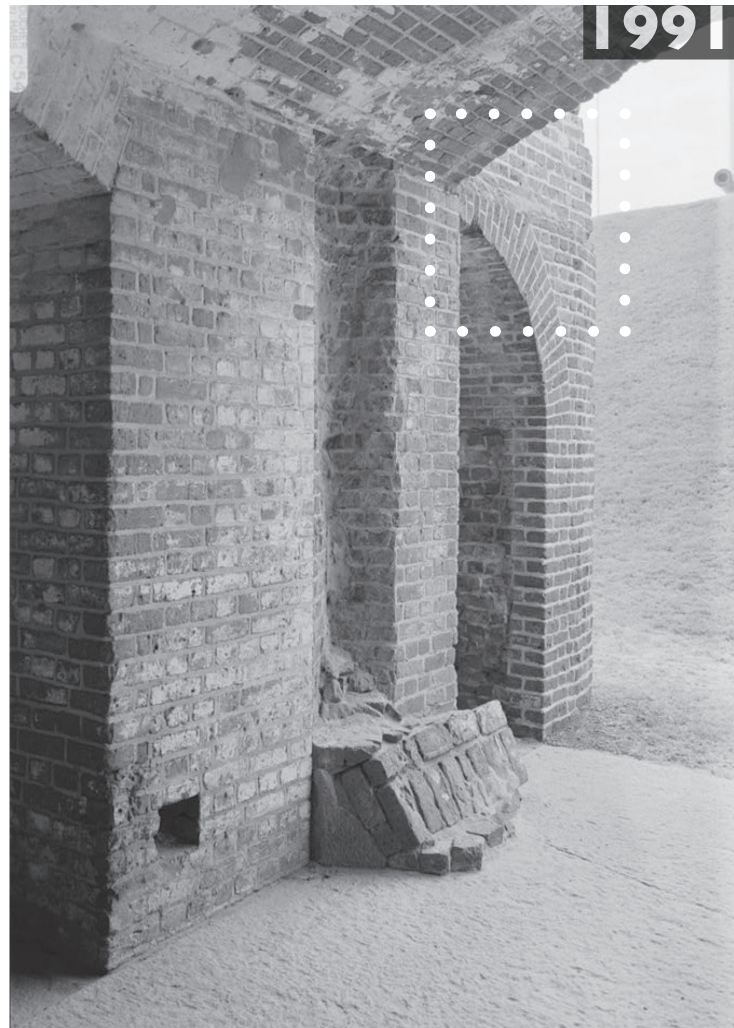
**OBSERVATIONS**

- The roofing material appears to be consistent from 1991 to 2013.

**CONDITION DETAIL**

SITE LOCATION







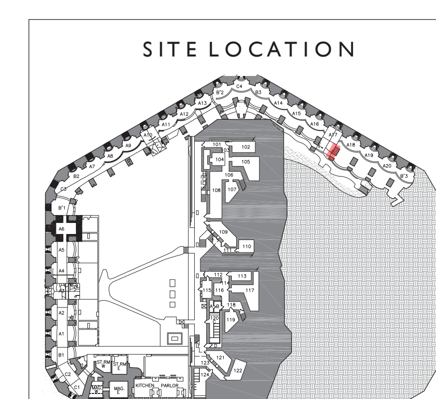
## LOCATION

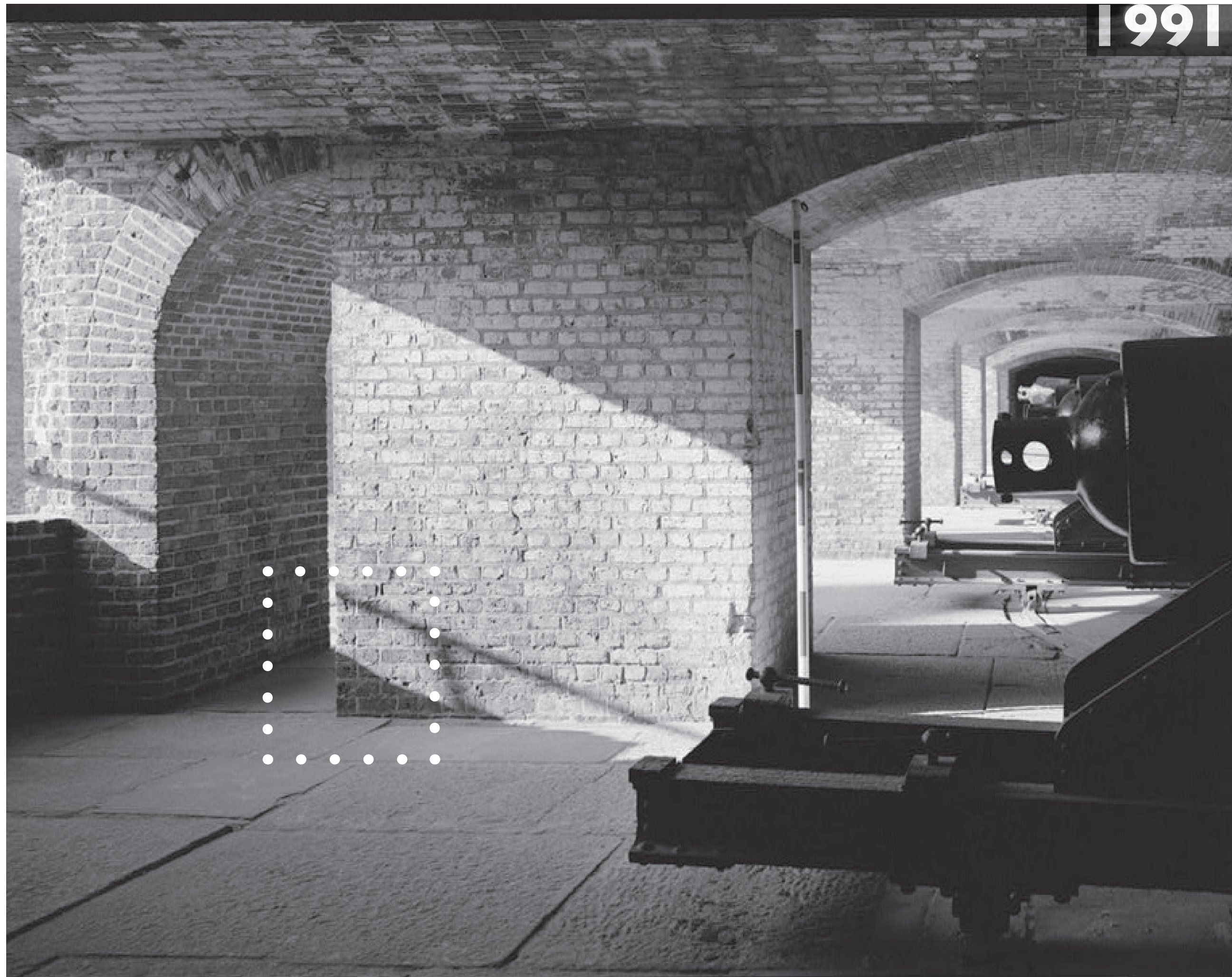
Right Face Casemates, detail view of the southeast wall leading out of Casemate A-17. [Credit: Historic American Buildings Survey]

## OBSERVATIONS

- Many of the white finishes on the brick masonry have remained predominantly intact since 1991.

CONDITION DETAIL







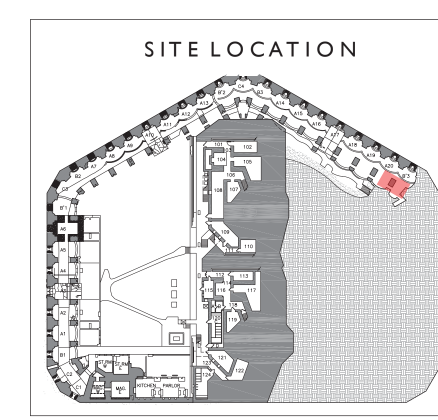
**LOCATION**

Right Face Casemates, from Casemate B'3 looking towards the salient angle through the casemates. [Credit: Historic American Buildings Survey]

**OBSERVATIONS**

- Many of the white finishes on the brick masonry have remained predominantly intact since 1991.

**CONDITION DETAIL**



# Appendix F: Fort Sumter Technical Document Review

This appendix contains a review of technical documents included in a non-traditional draft Historic Structure Report (HSR), unrelated to this 2015 HSR, prepared in 2011 for Fort Sumter. The 2011 draft HSR was canceled before it was completed; however, the technical studies contained therein remained part of the park's conservation strategy and therefore warranted a comprehensive review.

The 2011 draft HSR provides an overview of the history of Fort Sumter and attempts to describe the physical structure and its existing conditions. A substantial portion of the document is dedicated to an evaluation of the fort's building materials and the perceived threats to which these materials are subjected. This information is included in the text of the draft HSR and as a series of appendices and is the primary focus of the following document review.

The following review was performed by a team of historic building materials specialists including: Dorothy Krotzer, BCA Regional Director; George Wheeler, PhD, BCA Director of Scientific Research and Director of Conservation Research at Columbia University's Graduate School of Architecture, Planning, and Preservation; and John Walsh, President/Senior Petrographer and Magdalena Malaj Senior Chemist of Highbridge Materials Consulting, Inc.

The goal of this document review is to provide a critical assessment of the technical portions of the 2011 draft HSR. It provides an overview of the previous technical work, including an evaluation of the methodologies used and conclusions drawn. Although the review focuses primarily on information included in the draft HSR's appendices, it also provides general comment on the existing conditions assessment and proposed treatments presented in the body of that HSR.

Review of the appendices resulted in the identification of nine areas of concern related to the accuracy, validity and usefulness of the information presented in these sections. Section 4.0 of this report outlines these nine areas of concern and is supplemented by the document review provided by Highbridge included in Attachment A of this report. This document closes with a series of conclusions and recommendations for next steps.

# Fort Sumter

## Technical Document Review

Charleston, SC

May 2015

BUILDING CONSERVATION ASSOCIATES INC

# Fort Sumter

## Technical Document Review

Charleston, SC

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**CONTENTS**



ATTACHMENT A:
“Historic Structure Report, Fort Sumter National Monument Document Review” Prepared by Highbridge Materials Consulting, Inc. April 30, 2012.

## 1.0 INTRODUCTION

At the request of Joseph Oppermann, FAIA, of Joseph K. Oppermann - Architect, P.A., Building Conservation Associates, Inc. (BCA) performed a review of technical documents included in a non-traditional draft Historic Structure Report (HSR), unrelated to this 2015 HSR, prepared in 2011 for Fort Sumter. The draft HSR was canceled before it was completed; however, the technical studies contained therein are currently part of the park's conservation strategy and therefore warrant a comprehensive review.

The 2011 draft HSR was prepared for the Cultural Resources Division of the Southeast Regional Office of the National Park Service (NPS). The primary draft HSR team consisted of Liollio Architecture, NPS staff persons from Fort Sumter National Monument, Clemson University's National Brick Research Center, and Environmental Resources Management. The 2011 draft HSR provides an overview of the history of Fort Sumter and attempts to describe the physical structure and its existing conditions. A substantial portion of the document is dedicated to an evaluation of the fort's building materials and the perceived threats to which these materials are subjected. This information is included in the text of the draft HSR and as a series of appendices and is the primary focus of the following document review.

The following review was performed by a team of historic building materials specialists including: Dorothy Krotzer, BCA Regional Director; George Wheeler, PhD, BCA Director of Scientific Research and Director of Conservation Research at Columbia University's Graduate School of Architecture, Planning, and Preservation; and John Walsh, President/Senior Petrographer and Magdalena Malaj Senior Chemist of Highbridge Materials Consulting, Inc. Ms. Krotzer provided comment on Part I – Developmental History and Part II – Treatment and Use, as well as the recommendations for conservation mortars proposed in Appendix K – Guidance for Conservation Mortars. Highbridge focused on the technical data and interpretations presented mostly in Appendix B – Materials Evaluation Report of the draft HSR, while Mr. Wheeler focused on issues related to salt distress.

The goal of this document review is to provide a critical assessment of the technical portions of the 2011 draft HSR. It will provide an overview of the previous technical work, including an evaluation of the methodologies used and conclusions drawn. Although the review focuses primarily on information included in the draft HSR's appendices, it also provides general comment on the existing conditions assessment and proposed treatments presented in the body of that HSR.

The organization of the document review parallels that of the 2011 draft HSR. It begins with a general evaluation of the conditions assessment and proposed treatment sections of the draft HSR and then delves into a more specific review of the technical appendices. All eleven appendices in the draft HSR were reviewed with the exception of the following: Appendix F - List of Pertinent Documents and Valuable References; Appendix G - Glossary; and Appendix H - Treatment at the Component Level and Integration with FMSS. Review of the appendices resulted in the identification of nine areas of concern related to the accuracy, validity and usefulness of the information presented in these sections. Section 4.0 of this report outlines these nine areas of concern and is supplemented by the document review provided by Highbridge included in Attachment A of this report. This document closes with a series of conclusions and recommendations for next steps.

## 2.0 REVIEW OF PART 1: DEVELOPMENTAL HISTORY

The draft HSR's Part 1 – Developmental History is dedicated to the developmental history and overall condition of Fort Sumter. It discusses the historical background and context of the site, as well as its chronology of development and use. This section also provides a physical description of the fort, a condition assessment with supporting graphic documentation and an overview of the fort's character-defining features. Although much of the information presented in Part 1 falls outside of the scope of this review, there needs to be some discussion of the portions related to the fort's physical description and conditions assessment, as both of these topics are directly linked to the materials information presented in the appendices.

A key part of any HSR is the physical description of the building and its condition. This description is typically coupled with a discussion of the building's character-defining features and the extent of their physical integrity. Conditions assessments are usually carried out in a systematic manner, discussing the interior and exterior separately. For the exterior, each elevation is usually addressed individually and, for the interior, each space is described separately. Results of materials analysis, such and mortar analysis or paint analysis, are woven into the description and physical assessment to help shed light on specific conditions or explain the way a particular feature may have appeared historically. The materials analysis is intended to support and supplement physical conditions viewed on site.

Fort Sumter is admittedly a unique building type that may require a non-traditional approach for the assessment and recordation of its physical conditions, and the draft HSR clearly tries to tackle the complexity of the site by presenting the results of the conditions assessment and character-defining features survey in a tabular form. While this approach may have been appropriate for the survey itself and for the collection of raw data, the lack of any synthesis diminishes its usefulness. There is no explanation of why certain features are considered character-defining, where these features are located within the larger context of the fort, or their condition and degree of integrity. Similarly, there is no "big picture" discussion of the fort's conditions, just abbreviated physical descriptions and general notes regarding the feature's condition listed in tabular form. The "Physical Description, Condition Assessment, Character-Defining Features" section of the draft HSR unfortunately falls short of providing the type of comprehensive overview of key features, their condition and their degree of integrity that is usually a crucial component of any HSR.

The "Existing Conditions Graphics" also lack the level of comprehensiveness typically included in an HSR to document the location and extent of various conditions. In addition to not being comprehensive, the conditions that are documented graphically on the drawings are not necessarily the most relevant. Although major cracks and some losses in masonry are noted, there is a surprising lack of other conditions consistently noted. The photographs are also limited in terms of the information they contain. They are primarily general views of portions of the fort, but do not show specific conditions and are not annotated to describe content in any way. The authors seem to interpret the concept of "existing conditions" to mean current configuration or appearance, and not actual specific conditions that relate to structural or material problems.

Graphic documentation of condition assessments serves as an important counterpart to the written description of the building, as it allows for a visual depiction of the conditions. This visualization of conditions can aid in establishing patterns and linking conditions with location-

specific causes. It can also be useful in correlating a site's character-defining features with issues of condition and levels of integrity, information that can be used to inform treatment and interpretation strategies. Because the "Existing Conditions Graphics" included in the draft HSR lack thorough and consistent documentation of relevant conditions, they are not particularly useful as a record of the fort's conditions and cannot be used to inform treatments or interpretation.

The "Physical Description, Condition Assessment, Character-Defining Features" section of the draft HSR also fails to integrate into the larger document the findings of the technical studies presented in the appendices. Much of the technical study performed as part of the draft HSR is dedicated to trying to better understand the materials at the site as well as the conditions that may be negatively impacting them. Not tying the information from these studies into the larger discussion of condition, deterioration and long-term preservation is a missed opportunity for the draft HSR. The lack of integration also makes the appendices act as a stand-alone document, with no relationship to the other materials presented in the draft HSR.

In summary, the "Physical Description, Condition Assessment, Character-Defining Features" section of the draft HSR could have been vastly improved if two additional steps were undertaken:

- The information collected through the conditions assessment and feature inventory should have been synthesized in some way, not merely listed in tabular form. Synthesis would have allowed for a better overall understanding of the fort's features and conditions, with the possibility of linking the conditions to root causes. Information gathered through the technical analyses should also have been integrated into the discussion of the physical materials and their condition.

- The graphic representation of the actual conditions should have been more thorough and more consistent. Mapping of conditions allows the extent and location of problems to be better understood, allowing patterns to be established and possible causes to be identified.

## 3.0 REVIEW OF PART II: TREATMENT AND USE

Part II of the 2011 draft HSR focuses on the ultimate treatment and use of the site. As described in the NPS's *Preservation Brief 43 – The Preparation and Use of Historic Structure Reports*, an appropriate approach for the treatment for an historic site is selected once the site's history, significance and physical condition have been thoroughly investigated. In *Preservation Brief 43*, "treatment" is defined as the general approach adopted for a site as it relates to its interpretation, preservation, maintenance and repair. The *Preservation Brief*, as well as the *Secretary of the Interior's Standards for the Treatment of Historic Properties*, identify four basic treatments for historic sites: preservation, rehabilitation, restoration or reconstruction. Typically, a single treatment approach is selected to guide all future work on the building, from interpretive plans to repair programs. A single approach is usually selected to avoid inappropriate combinations of work, such as restoring a building's appearance to a specific point in time while simultaneously preserving portions as a ruin or constructing a new addition. A single preservation philosophy should guide all managerial decisions regarding a site's interpretation, repair and preservation.

Part II of the draft HSR does not address this issue of selecting an over-arching treatment philosophy for the site as a whole. Instead, it presents excerpts from various NPS management and planning documents for Fort Sumter that touch on the issue without providing a clear recommendation for a comprehensive treatment approach for the site. The section dedicated to development of a general treatment approach is, in fact, quite sparse. The bulk of the draft HSR's Part II – Treatment and Use is focused on the identification of specific threats to the masonry and recommendations for ways to mitigate these threats. In the draft HSR, the notion of *treatment* is taken quite literally to mean a repair strategy for specific threats (not necessarily conditions) as opposed to a philosophy or general approach for the entire site. However, only after a general philosophical treatment approach is identified for a site can specific work recommendations be made to address problematic conditions. This approach ensures that the work recommendations are consistent with the selected treatment.

The majority of this section of the draft HSR is dedicated to a table entitled "Treatment at the Asset Level: Alternatives and Interim Steps." As stated above, assigning treatments for various threats at this point in the course of the study of the site is felt to be premature. There are still many lingering questions related to the causes of the threats mentioned in this table, as well as the extent and location of the conditions related to these threats. While the materials analysis presented in the appendices attempts to answer some of these questions, the results are not always conclusive nor are they comprehensive; and in some cases, they are inaccurate (as discussed later in Section 4.0 of this report).

Repair treatments should not be developed until the causes of the conditions are fully understood and a comprehensive treatment philosophy is developed for the site. For instance, should a "surface sealer " be recommended for brick that has deteriorated due to salt contamination (Threat No. 3) without fully understanding the type or source of salts, or without evaluating the effectiveness or long-term impact of such a treatment on salt-laden masonry? By the same token, should a single re-pointing mortar be used for the entire site to achieve "uniformity of the wall and joint appearance" (Threat No. 30) or might the treatment philosophy for the site warrant the use of more than one pointing mortar as it relates to period of construction?

Because of the premature nature of the repair recommendations presented in Part II – Treatment and Use, they will not be evaluated for technical merit or their consistency with preservation standards as part of this review. A better understanding of the threats, their cause and the extent of their impact on the physical structure needs to be developed (in conjunction with a treatment philosophy) before specific repair treatments can be identified. However, some general comments and recommendations for improvement can be made about the information included in the "Treatment at the Asset Level: Alternatives and Interim Steps" table.

- Many of the threats identified in this section are legitimate and merit further study. The attempt at prioritizing the threats is also helpful. However, it would have been useful to also include the *conditions* associated with each of these threats and their *location* on the fort in this overview of threats that the fort faces. This information could also be presented graphically on the existing conditions drawings. This type of documentation would allow for a more comprehensive understanding of the extent and possible causes of various conditions and guide treatment options. It would also allow for a correlation with issues of significance and integrity for the site.

- Much like the "Physical Description, Condition Assessment, Character-Defining Features" section in Part 1 of the draft HSR, there is a lack of synthesis of the threats presented in this section. In addition, the type and scale of identified threats ranges widely, from wave action on the entire exterior face of the fort to localized areas of organic growth. It would have been more effective to distill and discuss the core issues facing the fort in a narrative form. The source of the problem should be better explained, as should its effect and resulting condition. Such a discussion could potentially allow for an improved understanding of the issues that are critical to understand the site's long-term preservation and interpretation.

## 4.0 REVIEW OF APPENDICES

### 4.1 General Discussion

All eleven appendices included in the 2011 draft HSR were reviewed as part of this study, with the exception of the following: Appendix F - List of Pertinent Documents and Valuable References; Appendix G - Glossary; and Appendix H - Treatment at the Component Level and Integration with FMSS. The review revealed several areas of concern in terms of the accuracy, validity and usefulness of the information presented. These key areas of concern, which are discussed in general terms below and in greater detail in the report provided by Highbridge included in Attachment A of this report, are related to the following topics:

- Synthesis
- Sampling Strategy
- Testing Protocol
- Compositional Analysis
- Lack of Appreciation for Practical Aspects of Masonry Construction
- Selective Interpretation
- Accelerated Durability Tests
- Salt Distress
- Conservation Mortar Recommendations

As the above-identified areas of concern suggest, the review team had substantial misgivings about the information presented in the draft HSR's appendices. The reviewers feel that, for the most part, the draft HSR's technical information is inaccurate and the technical data included in the appendices is misinterpreted. The test methodologies used by the 2011 draft HSR team do not follow accepted standards in the materials conservation field. Throughout the appendices, interpretations are based on minimal data and are therefore overextended. The combination of these factors unfortunately yields a document that has very little use in terms of forming the basis for future research. While some of the conclusions may be correct, additional research following accepted practices would be required in order to confirm them.

### 4.2 Synthesis

The lack of information synthesis, previously discussed in Sections 2.0 and 3.0 of this document, is a problem that extends throughout the draft HSR and into the appendices. The "Fort Sumter Threats Analysis Table" presented in Appendix A is no exception. This table elaborates on the threats presented in Part II – Treatment and Use and, like the earlier presentation of this information, it lacks any correlation between condition, threat, location and treatment. The table included in Appendix A is organized by threat (thirty-two are identified and are the same as those presented in Part II of the draft HSR). The location by component is included for each threat, as are four factors to be considered in evaluating the threat: materials, service environment, structural application and construction methods. All of these factors are important to consider in the evaluation of the potential threats that the fort is exposed to, but some degree of synthesis is necessary if this information is to be used for a more comprehensive understanding of what is going on with the fort *as a whole*. This appendix lacks a "big picture" diagnosis of the fort and its most significant threats and critical conditions. While the information to achieve a more comprehensive diagnosis may be included in this table, it gets lost in the abbreviated nature of the table presentation.

The table included in Appendix A is, in some ways, more useful than the table included in Part II of the draft HSR, which discusses "Treatment and Use". The "Fort Sumter Threats Analysis Table" in Appendix A includes baseline information about the masonry affected by each threat, including its location, environment, history and construction methods. There is quite a bit of useful information included in this table, which could be digested to produce a useful discussion of threats and possible causes. Instead of a synthesis of this information and a speculation of causes, the authors choose to jump to the development of repair recommendations. Developing specific solutions to address the threats that the fort is exposed to is premature due to the overall lack of understanding of the fort's conditions and their causes.

### 4.3 Sampling Strategy

The sampling strategy used throughout the materials analysis research does not follow industry standards and is considered inappropriate for several reasons. First, the quantity and size of the samples is too small for the type and extent of testing performed. Secondly, large amounts of data are derived from this inadequate sample pool. This large amount of data based on minimal samples brings into question the accuracy of the results and also creates the false impression that much more is known about the fort's materials than is actually the case. Lastly, samples appear to have been taken without regard for context and it is unclear how representative the samples are of the fort's overall materials. At the very least, the draft HSR should have included an introductory statement about the limitations of the sampling and the resultant data to prevent the information from being used as representative in future research efforts.

The very small number of total samples for the materials testing is troubling. It appears that a total of six mortar samples, possibly seven bricks, and a variety of miscellaneous construction materials samples comprise the complete sampling pool for the materials analysis section of the appendices. This quantity of samples is considered extremely low for a site of the size and complexity of Fort Sumter. Adequate sampling is often a challenge for historic buildings where there is a desire to minimize impact on fabric. However, larger structures such as Fort Sumter sometimes allow for a more liberal sampling plan. Additional sampling would be necessary to satisfy the stated goals of the analysis, namely the characterization of materials by identifying their chemical and physical properties, determination of wear mechanisms leading to deterioration and correlation of forensic information with macroscopic observations on the fort.

For the brick in particular, the poor sampling procedure is problematic since standard deviations for historic brick are so great. One can only assume that the data based on single specimens presented in the draft HSR deviate significantly from a true average and reporting this data in such a conclusive way is misleading. The results of the mortar analysis included in the draft HSR are also questionable due to the inadequate sample quantity and size (though there is no explicit summary of sample sizes or weights for the mortars examined so this information has to be inferred through descriptions and photographs). The apparent sample sizes do not meet the requirements of ASTM C 1324 – Standard Test Method for Examination and Analysis of Hardened Masonry Mortar, which suggests a minimum sample size of 10 grams for petrographic and chemical analysis.

If there is considered to be too little material to perform the work associated with ASTM C 1324, then it is even more concerning that additional testing beyond ASTM C 1324 was performed on the same sample quantity. The draft HSR states that select mortar samples were subjected to multiple destructive tests (destructive meaning that the same sample specimen

cannot be used for more than one test). The ability to perform this many tests on so little sample is dubious and, in addition, it is simply impossible for there to be any accuracy in the test results based on the inadequacy of the sample size.

The final issue related to the sample size and quality is that of the interpretation of salt damage. It appears that the mortar samples were taken as broken fragments or powder, thereby removing any context from the samples. Typically, mortar samples are examined from the exposed surface inward. In this way, it is possible to examine chemical changes in the mortar in relation to the depth of the joint. When a mortar sample is examined in this way, the following characteristics are usually visible: acidic decomposition of calcium carbonate at the surface; depth and distribution of carbonation; leach front and consequent porosity changes; and presence as well as location of secondary salt deposits and whether they are associated with micro-cracking resulting in surface mortar loss. Substantially more information could have been derived and verified had the samples been removed as intact slices from joints, with the exposed face noted. It would have been much more direct to look for the depth and distribution of salt distress petrographically, and then choose a testing protocol based on these qualitative findings.

## 4.4 Testing Protocol

There is an impressive array of tests applied to the materials addressed in the draft HSR, giving the impression that the materials are understood comprehensively. However, this approach can be characterized as a "buckshot" approach to testing, instead of a focused approach involving the use of select tests to answer specific questions. The selection of which tests to perform and which equipment to use seems to have been more a factor of what was readily available to the authors of the draft HSR than what would have been the most appropriate. Working with outside laboratories to perform other types of tests that might have been more appropriate does not seem to have been considered by the draft HSR authors.

Specific examples of the use of unnecessary or inappropriate testing is included in Highbridge's document review included in Attachment A of this report.

## 4.5 Compositional Analysis

Our review of the results of the compositional analysis included in Appendix B of the 2011 draft HSR indicates that the materials identifications and proportional estimates should be considered inaccurate, if not entirely incorrect. This is true for the results attributed to petrographic examination, mortar proportion determination and chemical analysis. Mistakes in identifications are common throughout the appendix and proper methods are not used to effectively measure each constituent and estimate their proportions. These mistakes can be primarily attributed to the inexpertness of the individuals performing the analysis. Therefore, any part of the draft HSR that relies on the identifications included in Appendix B should be re-assessed.

*Petrographic Examination*
Petrography is a highly-specialized field that requires formal training in the use of the polarized light microscope (PLM) and long-term experience in the petrographer's area(s) of expertise. PLM training includes identification of structure in two-dimensions, behavior of polarized light transmitted through crystalline materials and the semi-quantitative and/or statistical application of this behavior to the identification of mineralogical species. This training usually occurs at the undergraduate or graduate level in a formal geology program.

Long-term experience that develops from applying the learned methods on a regular basis to

problems in the petrographer's area of expertise is also important. Years of hands-on experience are required to fully appreciate the complexities in the microstructure of binders and composites, such as historic mortars and concrete. These skills are so important that ASTM C 856 – Standard Practice for Petrographic Examination of Hardened Concrete and ASTM C 1324 – Standard Test Method for Examination and Analysis of Hardened Masonry Mortar both require that qualified users have a minimum education and experience sufficient to perform the level of materials analysis included in the draft HSR.

For the materials analysis portions of the draft HSR, the petrography appears to be performed by an unqualified individual and, as a result, erroneous interpretations are common. These misinterpretations are found in the descriptions of the mortar, as well as the concrete and parging. In addition, petrography is not used to verify interpretations in cases where doing so would have been a simple matter. Specific examples that illustrate this overall lack of experience with petrography are included in Highbridge's document review included in Attachment A of this report.

*Mortar Proportion Determination and Chemical Analysis*
Although specific mortar proportions are provided in the technical appendices, the draft HSR lacks an explanation of how the mortar proportions were actually determined. Standard protocol for chemical analysis (the technique typically used to determine mortar proportions) does not appear to have been used. If other methods were used, these are not described in the draft HSR. The lack of explanation of the analysis protocol not only places in question the validity of the results, but it also prevents future workers from reproducing the test regiment and results.

Specific examples of the lack of a coherent approach to the chemical analysis for determining mortar proportions, as well as incorrect interpretations of this data, are included in Highbridge's document review included in Attachment A of this report.

### 4.6 Lack of Appreciation for Practical Aspects of Masonry Construction

Significant technical reading on the subject of historic masonry appears to have been performed by the authors of the 2011 draft HSR during the course of preparing the document, as evidenced by the list resources included in Appendix F. While an understanding of the technical aspects and science of masonry materials and how they weather is critical, so is an appreciation for the practical considerations associated with masonry construction.

Unfortunately, the draft HSR lacks a fundamental understanding of the practical aspects of masonry construction, such as mortar design and placement. For example, there is no discussion of key features of mortar such as sand gradation, water content and its placement in the masonry units. Sand texture and gradation are important features of mortar, as they affect its workability, porosity and ultimately its bond capacity to adjacent masonry. Instead of integrating a discussion of these practical considerations into the document, there is an overemphasis and exclusive focus on technical data.

Specific examples of how the document emphasizes technical information without including a discussion of practical characteristics of mortar materials are included in Highbridge's document review included in Attachment A of this report.

## 4.7 Selective Interpretation

The 2011 draft HSR presents a linear stream of data and interpretation for each material and laboratory test with arbitrary comments on select pieces of data that support one concept or another. This organization of the report makes it difficult for the reader to assess the quality of the various conclusions. When the narrative is carefully studied, there is an uncomfortable amount of "cherry-picking" of small pieces of data to support an interpretation. In itself, there is nothing wrong with speculating on interesting pieces of data. However, there is a sense that most of the conclusions are based largely on these sorts of narrow speculations with few pieces of conclusive evidence.

Specific examples of conclusions based on speculation are cited by Highbridge in the document review included in Attachment A of this report.

## 4.8 Accelerated Durability Tests

Accelerated durability tests of mortar can play an important role in understanding deterioration mechanisms at play in historic masonry and also in developing appropriate restoration mortars for a historic building. These tests typically involve a carefully planned and executed regiment of testing, controls and the use of industry standards for factors such as cure time and conditions. The mortar durability tests performed as part of the draft HSR, as included in Appendix E, did not embrace any of these crucial components and, overall, they appear to have not been particularly well planned. One of the primary problems is the lack of control of the critical variables, a key part of any scientific experiment. Because of this fundamental flaw, the accelerated durability tests performed as part of the draft HSR effort cannot be used to make critical decisions at the fort, as the draft HSR proposes.

As discussed above, the draft HSR over-emphasizes technical theory at the expense of important practical masonry considerations; this is no different in the case of the mortar durability tests. For the durability tests, original water contents and mortar consistency are unreported and apparently uncontrolled. Water contents directly affect permeability, cohesive strength and durability. There is no attempt at standardizing the mixes through consistent water/binder ratio or control of mortar consistency as determined by either a measurable flow test or plunger penetration test. Achieving consistency in mortar samples would be the logical first step to ensure that the mortars and the results of the testing can be fairly compared to one another. Unfortunately, sample preparation was not executed in a controlled manner for the durability testing. This lack of control places in question the summary of performance data and suggested ranking of mortars presented in Appendix E.

Typical curing protocol for mortars is also neglected in the accelerated durability tests. For instance, the entire curing period for the mortar samples lasts only two weeks, a duration that is almost certainly insufficient. Initial moist cure typically required for cementitious mortars is also apparently omitted. In addition, a high carbon dioxide environment is used to accelerate carbonation of the mortar samples. However, the authors do not consider the fact that a saturated carbon dioxide environment, as opposed to a natural environment, may actually be corrosive to the mortars. And lastly, instead of checking carbonation and adequacy of cure directly through application of a pH indicator (a frequently used and easy to interpret method), the author relies on indirect measurement through Thermal Gravimetric Analysis (TGA). The methodology is overly technical and introduces unnecessary error.

The choice of immersion solutions to simulate corrosive environmental agents that the mortars

may be exposed to at the fort is also questionable, as they do not truly simulate conditions at Fort Sumter. For instance, hydrochloric acid was used instead of sulfurous acid, which would have more accurately imitated acid rain.

Additional discussion of the accelerated durability tests and questions raised by the testing program is included in Highbridge's document review included in Attachment A of this report

## 4.9 Salt Distress

The topic of salt distress is discussed primarily in Appendices A and B of the 2011 draft HSR. Both appendices make the argument that the damage to the brick caused by salts can be attributed to the reaction between sea water and components in the mortar – particularly portland cement.

In Appendix A – Threats Analysis, salts are identified as representing a "high" threat level and are related to three separate types of threats: "Threat No. 3 - High Salt Contamination Resulting in Brick Deterioration", "Threat No. 4 - Portland Based Repointing Mortar Acting as Barrier to Water/Salt Transfer Out of the Structure and Resulting in Brick and Mortar Deterioration" and "Threat No. 10 - Water Intrusion into Assembly Resulting in Masonry Deterioration with a Threat Level." Threat No. 3 implies that it is the extraction of calcium from the mortars by exposure to sea water that is contributing to the formation of salts and Threats No. 4 and No. 10 imply that it is the low permeability of existing (portland cement) mortars that is responsible for the deterioration.

Appendix B – Characterization and Forensic Studies of Construction Materials from Fort Sumter National Monument also indicates a direct connection between the deterioration of the brick and the use of portland cement mortars based on interaction with sea water. This correlation is made clear in the appendix's Executive Summary, which states: "It was found that sea water impingement on the Fort causes extensive solubilization of calcium and other salt species, resulting in successive removal of layers from the brick surface in a process called "blistering" or "scaling". Further, sea salts were responsible for mortar loss by a corrosion process in areas of water impingement or where there is rising damp in masonry…Salt related durability failures of bricks, as exacerbated by superimposed stress, will continue as long as existing portland cement based pointing mortars stay in place at the Fort."

Although there is a concerted effort in the draft HSR to connect the salt damage on the brick to the reaction between seawater and components in the mortar (particularly portland cement), there is little direct or reliable evidence provided to support this hypothesis. The authors also chose not to explore the notion that accumulation of salts in the masonry from seawater may be the significant source of deterioration. A detailed evaluation of the chemistry data related to salt distress is presented below.

From the perspective of physical properties, there is an indication that the water transport properties of some of the mortars may help to transfer salts from the mortar to the bricks. However, the authors misinterpret their data and come to the opposite conclusion. More research needs to be performed in order to better understand this relationship. A detailed evaluation of the data related to the physical properties of the mortars is presented below.

*Appendix B - Page 209*
The draft HSR cites that there is an excess of calcium generally believed to come from mortars, as well as sulfates believed to be from Portland cement in the mortars. In addition, solution of calcium from the mortar and its movement through the bricks is the physical process leading to formation of subsurface salt within the brick. The result is loss of facial volume from the brick. Therefore, calcium efflorescence is implicated in durability failure. However, the excesses in calcium could easily arise from the deposition of $CaCO_3$ or $Ca(OH)_2$ from any of the types of mortars, not just those based on portland cement. So, a direct correlation between the Portland cement mortars and salt damage to the masonry cannot be made based on the evidence presented in the report.

In addition, salt samples were removed from brick surfaces by transfer to tape, water extraction, and then ion chromatography. It should be noted that ion chromatography does not identify the crystallized species, but instead it identifies the soluble ions that can form a range of crystalline materials.

*Appendix B – Page 210*
According to the report, cryptoflorescence leads to damage exacerbated by superimposed stress from modulus mismatch between the brick units and portland cement mortars (modulus mismatch being the relative thermal expansion of materials in contact with one another). However, the report later indicates that the much of the portland cement mortar is soft, which seems to contradict the idea that it is imposing stresses on the brick. Furthermore, the possible modulus mismatch 6 versus 12 ($10^{-6}$) is not large enough to cause damage.

*Appendix B - Page 212*
The report states that there is evidence of solution of lime from mortar species and also that the mortars and bricks used in the fort are porous in nature. This statement supports the conclusion presented above that the excesses of lime could arise from the deposition of $CaCO_3$ or $Ca(OH)_2$ from any of the types of mortars, not just those based on portland cement.

*Appendix B - Page 213-214*
According to the report, the Scanning Electron Microscopy (SEM) images on page 213 show sodium chloride and ettringite. However, these identifications are not definitive, as there is no accompanying elemental data for either. Typically, elemental data (or EDS) is provided along with the SEM images to identify the elements (and therefore the compounds) present in the image. This report does not include that elemental identification, so any information must be gleaned from the photographs alone. In addition, the bottom photograph included in Figure 3 on page 213 looks more like gypsum than either material identified in the report.

*Appendix B - Page 215*
According to the report, there is a protective layer of calcium sulfate over carbonate that dissolves in the presence of sodium and chloride (from sea water). However, the report does not show any evidence of this protective layer. In addition, if such a layer did exist, it would dissolve in the presence water and repeated wave action constantly present at the site, not just sea water.

*Appendix B - Page 243*
According to the report, Mercury Intrusion Porosimetry indicates that the Fort's mortars tested as part of this study are porous (approximately 24-44%), with the percentage of small (<1 micron) pores ranging from 6.5-83.1%. Earlier in Appendix B, in Table 5 on page 230, the report

states that the fort's bricks are 32-38% porous, with smaller percentages of small pores. The report interprets this data incorrectly, stating that "…this implies that all of the bedding mortar specimens exhibit higher capillary suction and water uptake than the bricks." However, uptake rates are actually much lower for materials with small pores, so water should move from the mortars to the bricks instead of the other way around, as the authors suggest. This evidence actually indicates that the mortars tested as part of this study may not be compatible with the bricks.

On page 243, the report also states that "Another observation is that Mortars 3 and 16 exhibit a very high content of fine pores suggesting that salt water infiltration influenced this result (via corrosion processes that typically result in high content of fine pores in materials)." However, this statement is offered as speculation and does not present any evidence to directly support this hypothesis.

*Appendix B - Page 249*
The report cites the following reaction products resulting from seawater corrosion of historic mortars (as identified by XRD). An evaluation of these results is provided below.

- Specimen 3: brucite, iowaite, and bassanite
- Specimen 5: sodalite
- Specimen 11: sylvite (or halite)
- Specimen 16: epidote

For Specimen 3, the identification and interpretation of brucite, iowaite, and bassanite as being present in the mortar solely due to a reaction with seawater is questionable. For example, the brucite detected in the sample specimen could be a hydration product of natural cement present in the mortar originally as opposed to being the result of cement reacting with saline water. Brucite is low in solubility and does not carbonate, so it is typically retained in the mortar. Iowaite, which is also documented as being present in Specimen 3, is found in Pre-Cambrian serpentinites and cannot form under conditions present at Fort Sumter. The peaks in the diffraction pattern identified as Iowaite are more likely to be gypsum (as discussed below). And lastly, the presence of bassanite is also unlikely. Bassanite will not survive in any environment containing water, as it is the equivalent of Plaster of Paris and will convert to gypsum immediately. The compound identified could have been gypsum initially, which was converted to bassanite upon heating during sample preparation. Therefore, there is no evidence in the diffractogram provided for Specimen 3 to support the reaction between sea water and mortar components.

For Specimen 5, there are similar problems with the identification of sodalite in the mortar. Sodalite is a framework silicate that only forms from solidification of magma or other special geological conditions, so its presence is unlikely. Furthermore, the diffractogram for this sample specimen is not shown for evaluation. Therefore, there is no evidence in the XRD analysis of Specimen 5 to support the reaction between sea water and mortar components.

For Specimen 11, the report states that the identified material is either sylvite or halite, or a mixture of the two. However, the diffractograms for sylvite and halite are quite different. The 100% line for sylvite is at 3.14 angstroms and for halite it is at 2.82 angstroms. Therefore, they cannot be confused with each other in XRD. Unfortunately, the diffractogram for this sample is not shown for evaluation. The presence of either sylvite or halite indicates seawater infiltration,

but this does not necessarily provide evidence to support a corrosive reaction between sea water and mortar components.

For Specimen 16, epidote is identified as a reaction product from sea water corrosion. However, epidote occurs in low-to-medium grade (usually regional) metamorphic environments and cannot form under the conditions present at Fort Sumter. Therefore, there is no evidence in this diffractogram to support the reaction between sea water and mortar components.

*Appendix B - Pages 274 and 275*
XRD results indicate that ettringite and thaumasite are present in the whitewash sample that was examined. The report suggests that the presence of ettringite and thaumasite indicates "corrosion with environmental sources of sulfate." However, the 100% lines for both of these species are absent from the diffractogram, so neither of these species can be present in the whitewash. Therefore, there is no indication of any environmental sources for the "corrosion" of the white wash.

## 4.10 Conservation Mortar Recommendations

The intention of Appendix K - Guide for Conservation Mortars is to provide an overview of the philosophical and technical considerations for selecting an appropriate mortar for an historic site, with a focus on restoration mortars for Fort Sumter. The discussion is both general (when discussing the philosophical issues) and specific (when discussing the mortar formulations that the authors believe should ultimately be used at Fort Sumter).

The beginning of the appendix reviews two NPS publications, *Preservation Brief No. 2: Repointing Mortar Joints in Historic Masonry Buildings* and *The Secretary of the Interior's Standards for the Treatment of Historic Properties*. While the *Preservation Brief* is an appropriate document to refer to for guidance in the selection of restoration mortars, the *Secretary of the Interior's Standards* really is not. The Standards are intended to be applied to larger questions of appropriate philosophical treatments or approaches for an historic site, not what mortar is appropriate for use in a restoration. Mortar is generally recognized as sacrificial and as a material that requires routine replacement. To assign historical significance and identify a mortar as a distinctive feature of an historic site is not appropriate.

In addition, while it is important to know what types of mortars were used historically on a building, this is not done for the exclusive purpose of replicating exactly what was there. One needs to also look at how these mortars have performed over time and if they are worthy of replication. Oftentimes, replication of a mortar using the same components and in the same proportions is not desirable because the mortar has not served the building well or has actually been damaging to the masonry in some way. The fact that a mortar was used on a building historically is not the sole justification for its replication.

The appendix continues by discussing the specific mortar mix that should be used at Fort Sumter. This mix is identified as a combination of Rosendale natural cement, hydrated lime and sand, in proportions to vary according to location. While such a mix may in fact be appropriate for the fort in terms of historic precedence and also overall durability and compatibility with the masonry, the technical information presented in the draft HSR is not sufficient to support this recommendation.

The technical data presented in the draft HSR is insufficient for the purpose of developing an

appropriate restoration mortar for two primary reasons. First, the identification of both natural cement and lime in the historic mortars is questionable. As discussed previously in Section 4.5, much of the compositional analysis performed to identify the original binder materials as natural cement and lime is believed to be inaccurate. The identification of lime in the Fort Sumter mortars is particularly questionable. Additional testing and examination by professionals with specific experience in the characterization of historic mortars would be required in order to confirm the findings related to mortar composition that are presented in the draft HSR. In addition, it is not clear why Rosendale natural cement is specifically chosen for the restoration mortar, as opposed to another American natural cement from a different source.

Secondly, not enough testing has been done to identify the effects of the various conditions present at the fort on the brick and mortar. The draft HSR recognizes the importance of doing this type of research, but the testing program falls short by not following standard testing protocol for the forensic studies performed as part of Appendix B nor for the mortar durability tests performed as part of Appendix E.

Lastly, more information is needed on the bricks themselves and what mortar would be best suited for their long-term preservation. A more thorough testing program should be implemented to look at the characteristics of the bricks and what mortar would be the best match for them given the specific conditions present at the fort. This testing regiment should include a wide range of mortar types and should look at key properties such as strength, water vapor transmission and capillary uptake. The authors of the draft HSR indicate the preliminary nature of their testing in Appendix K and how little substantial information exists on potentially appropriate mortars for Fort Sumter when they state: "Appendix E shows the results of a simple, preliminary experiment…This experiment was small in both scope and funding…This experiment will be expanded in scope and rigor in late 2010 and early 2011. Results of this continuing experimentation will inform the specification of mortar mixes for use at Fort Sumter." They go on to say, when discussing whether a natural cement based mortar is appropriate for the brick masonry at Fort Sumter: "Is contemporary Rosendale compatible with historic brick? No one yet has proven otherwise, though some questions about this have arisen, and research on these points is in progress." For the authors to point out such caveats and the limited scope of the research to date confirms that the selection of a specific repair mortar for the fort is premature.

Appendix K - Guidance for Conservation Mortars could be improved if the following steps are undertaken:

- The references to the *Preservation Brief No. 2: Repointing Mortar Joints in Historic Masonry Buildings* and "The Secretary of the Interior's Standards for the Treatment of Historic Properties" should have been synthesized in some way to provide general and philosophical guidelines for the development of appropriate conservation mortars. The format would be more effective if it was in a narrative form instead of a series of questions and answers. In addition, there should be less of an emphasis on Rosendale natural cement as a "distinctive" material as defined by the Standards, as this is not an appropriate application of the Standards.

- A specific mortar type (namely one based on a combination of Rosendale natural cement, hydrated lime and sand) should not be included in this section since there are still so many questions to be answered about the composition of the historic mortars, the characteristics of the historic brick and the durability of various restoration mortar

formulations when subjected to the conditions at the fort. The authors of the draft HSR admit that research is ongoing and is not conclusive, yet they recommend a restoration mortar. This recommendation is premature.

- The information included in the last column of Table 37 (the column entitled "National Brick Research Center 2010") should not be presented as definitive and consideration should be given to removing it from the table all-together. As discussed previously in this document review, the data generated as part of the draft HSR research for properties such as physical strength, porosity and bulk density is not considered to be definitive due to the testing methodology and sampling protocol that was used. Presenting the information in such a conclusive way is misleading. In addition, it is not practical to expect that every replication mix would be subjected to the tests indicated or that they would meet all of the properties specified. Lastly, the coupling of the specific numerical values for certain properties with the general, more practical guidelines of the other two columns (based on NS Preservation Brief No. 2 and ASTM C 1713) makes the table less useful. It would be better to list the general requirements of the first two columns and omit the information of the third.

## 5.0 CONCLUSIONS AND RECOMMENDATIONS

This review, which focuses primarily on the technical portions of the 2011 draft HSR, reveals a document that is lacking in three primary ways. First, the draft HSR fails to provide solid and accurate documentation of the fort's historic materials. As discussed in previous sections, the results presented in the appendices are believed to be substantially inaccurate due primarily to poor sampling strategy and misinterpretation of data. Secondly, the draft HSR makes recommendations for treatments prematurely. And thirdly, the draft HSR lacks any type of synthesis of information related to the fort's materials and physical condition.

For all three reasons, the technical aspects of the draft HSR will need to be revisited on a large scale and their content significantly revised. It will be particularly important to revisit the results of the technical analysis presented in the appendices if they were used to inform conservation strategies or treatment recommendations, since any misinterpretation of existing materials could significantly affect any proposed treatment plan.

If there is an opportunity to revisit the technical aspects of the draft HSR, the following steps should be taken to produce a more useful and appropriate document:

- Archival research and a visual assessment of the fort should be performed in order to gain a basic understanding of the fort's materials and their performance. The combination of these two types of research will provide a baseline understanding of the materials that are present at the fort and their condition. It will be important to perform the visual assessment using accurate drawings or photographs to record conditions. Such graphic representation of conditions will allow the location and extent of various problems to be better understood, while also linking conditions to certain threats or types of exposure based on location. The graphic documentation will also allow patterns of specific conditions to be established.

- The information collected through the archival research and conditions assessment should be synthesized in order to provide an overall understanding of the fort's features and its conditions, with the possibility of linking the conditions to root causes. This synthesis of information should be discussed in the body of the report and supplemented, as necessary, by the results of laboratory testing and materials analysis.

- A targeted testing program to answer specific questions raised during the course of the archival research and conditions assessment phases should be developed. The testing program should involve a combination of techniques, both in the field and in the laboratory, with the primary goal being to support and supplement physical conditions viewed on site. Tests should only be executed to answer specific questions that will help better explain decay mechanisms and their sources. The results of the targeted materials analysis and laboratory-testing program should be fully integrated into the larger discussion of the fort's condition and the possible sources of these conditions. This will allow for a correlation between forensic information and macroscopic observations of the fort. While details of the testing program, including the methodology employed and the results, should be included as an appendix, it is critical that the information is also woven into the body of the report.

- For multiple reasons previously discussed, the majority of the technical data and results presented in the draft HSR are felt to be unreliable. As a result, the previously-performed materials research will need to be entirely revisited and tests that are felt to be worthwhile as part of any future testing program will need to be repeated. Additional research to confirm specific results may also be required. Any future materials research should be implemented according to industry standards and accepted practices in the conservation field, and by professionals with specific experience in the selected type of testing.

- Additional testing should also be performed to learn more about mortars suitable for use at Fort Sumter. Characteristics such as strength, water vapor transmission, capillary uptake, etc. should be examined. This testing program should follow standard testing protocol.

- Practical issues of masonry design should also be considered as part of the discussion of material condition and performance. Issues such as construction technique, mortar design and placement should be discussed along with observations related to condition and the results of materials analysis and lab testing. The latter information is most useful when viewed in combination with investigations of masonry design and installation.

- The development of specific treatments for the repair, maintenance and conservation of the fort's masonry materials should be postponed until the sources of various conditions and the threats that the fort faces are better understood. It is also crucial that treatment recommendations be developed in conjunction with an overall treatment philosophy for the site and its individual features. This approach would allow for a correlation between issues of material condition, significance and integrity.

- The "Fort Sumter Threats Analysis Table" included in Appendix A provides baseline information about the threats to which the fort's masonry is exposed. It includes information on areas of affected masonry, including their location, environment, history and construction methods. The information included in this table could serve as a springboard for a discussion of threats and possible causes, as well as the conditions that result from the various threats. Any such discussion should attempt to synthesize the information included in this table, elaborating on the identified threats and the resulting conditions.

- The core issues facing the fort should be distilled and discussed. Potential sources of problems should be well-explained to allow for an improved understanding of the issues that are critical to understanding the site's long-term preservation and interpretation.

## Attachment A

**"Historic Structure Report,**
**Fort Sumter National Monument Document Review"**

**Prepared by Highbridge Materials Consulting, Inc.**
**April 30, 2012**

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# HISTORIC STRUCTURE REPORT, FORT SUMTER NATIONAL MONUMENT DOCUMENT REVIEW

| | | | |
|---|---|---|---|
| **Client:** | Building Conservation Associates, Inc. | **Client ID:** | BUIL005 |
| **Project:** | Historic Structure Report | **Report #:** | SL0353-01 |
| | Fort Sumter National Monument | **Report Date:** | 04/30/12 |
| | Document Review | **Reviewers:** | J. Walsh (Senior Petrographer) |
| | | | M. Malaj (Senior Chemist) |
| | | **Page 1 of 12** | |

## 1. Introduction

On February 23rd, 2012, Highbridge was requested to perform a document review by Ms. Dorothy Krotzer of Building Conservations Associates, Inc. The document is a Historic Structure Report (HSR) for the Fort Sumter National Monument in Charleston, SC dated January, 2011. The review is requested in order to provide opinion on materials analysis and interpretation found in the appendices of the document. John J. Walsh (senior petrographer) and Magdalena Malaj (senior chemist) from Highbridge Materials Consulting are the reviewers for this report. Where this report refers to the author, this refers to the author of the particular section of the HSR under consideration.

## 2. Scope of Review

We have focused our efforts on a review of technical data and interpretations presented mostly in Appendix B. Other later appendices are referenced where appropriate. Opinions are also provided for Appendix E and K. We have emphasized many of the technical aspects of the testing with specific examples. Commentary is also offered regarding the applicability of methods and general testing approach.

The following are either excluded from or not emphasized in our review:

- The main body of the HSR is not reviewed. Our expertise is in materials analysis rather than architectural conservation and we are not commenting on historical data or the appropriate format for an HSR.
- We have not reviewed the Threats Analysis in Appendix A though some of our opinions of technical results may have a direct bearing on conditions reported in this section.
- We understand that Dr. George Wheeler will focus on issues related to salt distress. In order to minimize redundancy, we have omitted any general discussion of theories proposed in the HSR. Some specific technical points are made that relate to the interpretation of salt distress and these are left in bullet form so that the client may combine these with Dr. Wheeler's more comprehensive discussion if deemed appropriate.

**3. Executive Summary**

In our review of the technical appendices of the HSR, we find there is a disconnect between the analysis performed and the findings and interpretations of the document. To be sure, we do not disagree that natural cements were used in the construction of Fort Sumter or that salt distress plays a significant role in weathering of the scarp wall. These general interpretations may have been obvious from the historical documentation and a visual assessment of the structure. However, no conclusive evidence is presented despite a rather elaborate testing program.

We appreciate the desire to avoid destroying building fabric. However, the sampling is inadequate in quantity, quality, and size to ensure a sufficient level of analytical rigor. An excess of testing is applied to the few samples collected and little of it is directly applicable to the thrust of the analysis. Much of the testing appears to be geared toward an employment of instruments available rather than those that might provide more direct results. There is no systematic approach to the data gathering and the data presentation is unnecessarily liberal. Ultimately, many of the summary conclusions are supported only by selective interpretation of few data amongst the many gathered. In many cases, these selective interpretations themselves are considered questionable.

The compositional analysis of the original materials is considered inaccurate at best and probably incorrect in most cases. The qualitative methods used for identifications are performed inexpertly and mistakes are abundant. The quantitative methodology is not well described. However, simpler more direct methods are ignored in favor of an indirect instrumental approach that cannot partition the constituents accurately. Where these analyses bear on conservation strategies reported elsewhere in the HSR, it will be important to revisit these results to determine how critical a misinterpretation of extant materials affects any proposed treatment plan.

There is a general impression that the author is new to the field of historic masonry and has done quite a lot of technical reading prior to the HSR development. Where this manifests itself is in an overemphasis on technical matters at the expense of the more practical considerations of masonry design that are learned through direct experience. This imbalance is clear in the durability testing presented in Appendix E and the discussion of conservation mortars presented in Appendix K. In the former, field mixed mortars are subjected to various immersions but important basic variables such as mix water content and effective mortar curing are not effectively considered or controlled. In the latter, there is a suggestion that various impractical tests be used to evaluate repair mortars based on instrumental analysis not generally utilized or believed to be crucial by other experts working in the industry.

Unfortunately, we do not feel that the technical data presented provide a sufficient foundation on which to base future preservation efforts. There are some interesting academic findings but little that can be meaningfully interpreted. Future work on the document should be redirected to more practical issues of masonry design and performance before engaging in additional testing.

Respectfully submitted,

John J. Walsh
President/ Senior Petrographer

## 4. Sampling Strategy and Significance

- The number of samples is inadequate for the stated goals.
- Large (excessive?) amounts of data are derived from what should be considered specimens rather than representative samples.
- The size of any individual sample may be too small for the amount of testing performed and accuracy is likely compromised.
- Samples are taken without regard for context. Salt distress is examined without reference to depth within the joint.

It appears that a total of six mortar samples, possibly seven documented bricks, and a handful of miscellaneous construction materials samples comprise the complete sampling for the materials analysis section of the Appendices. Certainly, adequate sampling is an issue in historic preservation where there is a desire to minimize impact on fabric. However, larger structures such as the coastal forts often allow for a more liberal sampling plan and this would be necessary to satisfy the stated goals of the analysis. The bigger problem here is that the excess of data from a small number of samples gives the impression that much more is known about the represented materials. In fact, there is disproportionate amount of data gathering and testing given the quantity and quality of specimens. The samples are better referred to as specimens as they cannot be demonstrated to be representative of the larger whole. Appendix D hints at this problem at least for the brick but this is only found after the “Grand Summary” on page 277. A more explicit caveat should be offered possible as an introductory statement.

It would have been better to leave out the brick data presented in Table 5 on page 230 as there is a danger of these being used as representative in future efforts. We have had an opportunity in the past to sample and test a few dozen brick specimens from both Fort Adams and Fort Sumter and have run similar physical tests under ASTM C 67 and other methodologies. We have found that standard deviations for the historic brick are often several tens of percent of the average even where we have exceeded the minimum five specimen requirement of the ASTM standard. It has to be assumed that the single specimen data deviate significantly from a true average and reporting these can only be misleading.

The size of each mortar specimen appears particularly troubling though there is not an explicit summary of sample sizes or weights. Figures 24 and 25 on page 242 purport to exhibit the “range” of samples as-received. The author admits to having knowledge of ASTM C 1324 which covers only the compositional analysis of mortar samples. This standard suggests a minimum sample size of 10 grams to perform a petrographic and chemical analysis and experts using these methods consider even this amount difficult to work with accurately. An estimate of the sample sizes shown in the photographs suggests about 1 - 2 grams for Sample 11 and possibly 4 - 5 grams for Sample 6.

Sample 11 presents an example of how much data is attempted to be drawn from an inadequate sample. The following destructive tests were all apparently performed on the fragments shown in Figure 24:

X-ray diffraction analysis (pg. 250)
Insoluble residue (pg. 250)
X-ray fluorescence (pg. 250)
Mercury Intrusion Porosimetry (pg. 243)
Differential Scanning Calorimetry (pg. 251)
Soluble salts (ion chromatography) (pg. 251)
Petrography and SEM (presumably though not explicitly stated)

Setting aside whether the testing itself is appropriate or useful and whether it is even possible to perform this many tests on so little sample, it is simply impossible for there to be any accuracy in the test results based on the inadequacy of the sample size. Table A1 on page 308 suggest that 2 grams were used for chemical analysis and 2 grams for insoluble residue. This does not seem possible given the size of the sample shown.

Another issue regarding the sample size and quality is the interpretation of salt damage. It appears that the mortar samples were taken as broken fragments or powder thereby removing context from the samples. Typically, we choose to look at mortar samples from the exposed surface inward. In this way, it is possible to examine chemical changes in the mortar with depth. We can usually see the acidic decomposition of calcium carbonate at the surface, depth and distribution of carbonation, leach front and consequent porosity changes, presence and location of secondary salt deposits, and whether or not these are associated with microcracking resulting is surface mortar loss. Substantially more information could have been derived and verified had the samples been chosen as slices of mortar saw-cut from the represented joints. It would have been much more direct to look for the depth and distribution of salt distress petrographically and then choose a testing protocol based on these qualitative findings.

**5. Appropriateness of Tests**

There is an impressive array of tests applied to the several materials comprising the sample suite giving the impression that the materials are understood comprehensively. However, the technical reader might characterize this is a "buckshot" approach to testing where everything at the analysts disposal is used whether or not the data is applicable to the questions at hand. There is also an impression that the analyst is limited to only those tools available at that particular laboratory when other tests might be appropriate. Some examples:

- Modulus of elasticity of brick is determined using ultrasonic methods (pg. 237). This would provide a dynamic rather than static modulus and it is well understood that these values are not usually the same. Dynamic modulus represents the elastic response of a material under infinitesimal stress (sonic waves) whereas static modulus represents the elasticity under the loads potentially encountered in a structure. Admittedly, the dynamic data can be helpful if compared to similar results for masonry mortar with the intent to ensure greater flexibility in the mortar. However, no mortar data is provided or discussed so the usefulness of these data is not apparent. Of concern is the possibility that these data might be used in engineering assessments of the fort. In this case, static modulus would be critical and the dynamic modulus should not be used.
- In Table 11, the hygric expansion is determined for a brick specimen. While academically interesting, the value of these data is unclear. The author suggests that these data may be used in the selection of replacement brick. Assuming the in situ brick has already long since expanded due to rehydroxylation it is not clear why the original hygric expansion would be of any assistance in selecting a suitable replacement. More important would be an understanding of the static modulus of elasticity of surrounding materials such as mortar where stresses due to fresh hygric expansion of brick would potentially cause undue stress.
- Mercury porosimetry is used as a proxy for vapor permeability. If larger bedding mortar samples were taken it would have been possible to determine the vapor permeability through direct measurement (ASTM E 96). This direct method was not used anywhere in the report.
- There is an overinterpretation of X-ray diffraction data (pg. 249). Workers who regularly use XRD for the analysis of composites are familiar with the problem of a high quartz and calcite signal (Table 16) followed by one or two unusual and typically spurious phase identifications. The absence of other important phases should be a tip-off. For example, ferrite phases are not detected through the XRD analysis though they are clearly observed in the petrographic micrographs. The XRD signal for Specimen 6 detects only calcite and quartz despite the natural cement identification. The brucite detected in Sample 3 is likely a simple hydration product of the natural cement. Bassanite is unlikely and may be a misidentification of gypsum. Epidote is a moderate temperature geological mineral that is probably also an incorrect identification. It is concerning that the author tries to tie each phase to an interpretation without regard for the typical problems encountered using XRD for bulk analysis of composites.
- More is discussed on the tools used for binder identification and proportional estimates below.

### 6. Compositional Analysis

The materials identifications and proportional estimates are all done inexpertly. Mistakes in identifications are common and no proper method is used to effectively measure each constituent and estimate their proportions. The reported mixes for the existing materials must be considered inaccurate if not entirely incorrect. Any part of the HSR that relies on these identifications must be reassessed. To summarize:

- All constituent identifications and proportional estimates are considered dubious.
- Petrography is performed by an unqualified user and erroneous interpretations are common. These are described for the mortar below but similar arguments can be made for the concrete and parging.
- Petrography is not used to verify interpretations in places where this would have been a simple matter.
- Standard protocols for chemical analysis are entirely neglected. It is assumed the laboratory is not competent in the wet chemical preparations and does not possess the required equipment.
- X-ray fluorescence is performed repeatedly though these results do not appear to have been used. This either represents unnecessary data or there may have been a desire to use these to calculate mortar proportions using a method that was later abandoned.
- Binder chemistry is reported and compared to Rosendale cement but the reported chemistry actually represents the total mortar (binder plus sand). The mathematics are circular.
- Ultimately only insoluble residue, TG/DSC, and EDAX are used in a highly suspect manner to estimate proportions.
- If other methods are used, these are not reported and there is no ability to assess the validity of the results.

#### 6.1 Petrographic examinations

The petrographic microscope is not a simple black-box instrument used to magnify images. Petrography is a highly specialized field that requires two distinct skill sets. The first is a formal training in the use of the polarized light microscope (PLM) including identification of structure in two-dimensions, behavior of polarized light transmitted through crystalline materials, and the semi-quantitative and/or statistical application of this behavior to the identification of mineralogical species. This is a nontrivial training usually occurring at the undergraduate or graduate level in a formal geology program. The second skill set is simply the long term experience that develops from applying the methods on a regular basis to problems in the workers area(s) of expertise. There are simply too many complexities in the microstructure of binders and composites such as mortar and concrete that a new user cannot appeal to a photographic atlas of "typical" occurrences and hope to succeed. Years of hands-on experience are required to fully appreciate these complexities. These skills are so important that ASTM C 856 (for concrete) and C 1324 (for mortar) both require that qualified users have a minimum education and experience sufficient to do what the author is attempting to do in the materials analysis sections of the HSR. As the author refers to the use of ASTM C 1324, it should be assumed that he is aware of these necessary qualifications. Just as professional engineers have an ethical obligation to avoid presenting themselves as experts in disciplines in which they have limited experience, professional petrographers have adopted a similar mandate in our Code of Ethics (ref: Society of Concrete Petrographers):

> *The Society fosters a Code of Ethics for concrete petrographers. The Code of Ethics includes that: (1) concrete petrographers shall not engage in work in which they are not competent, unless under the guidance and direction of a concrete petrographer experienced and competent in that particular work, (2) concrete petrographers must meet the qualification requirements defined in the Qualifications Section of ASTM C856, "Standard Practice for Petrographic Examination of Hardened Concrete" (3) advice, opinions, and judgments shall be objective, consistent, and based on competency and experience in the matters involved and not in disagreement with technical and scientific principles.*

The author reveals a lack of experience throughout most of the petrographic discussion. Two basic examples from pg. 245 are given here:

> *"The sand is an assembly of very small crystals, and this microstructure was common to all sanded mortars examined in this study"*

What the author has misidentified as small crystals in Fig. 26 is the shattering of single quartz grains that occurs from aggressive thin section preparation. While this may seem minor it indicates a lack of understanding of several fundamental principles that would prevent the author from being able to interpret much else from his observations later in the report.

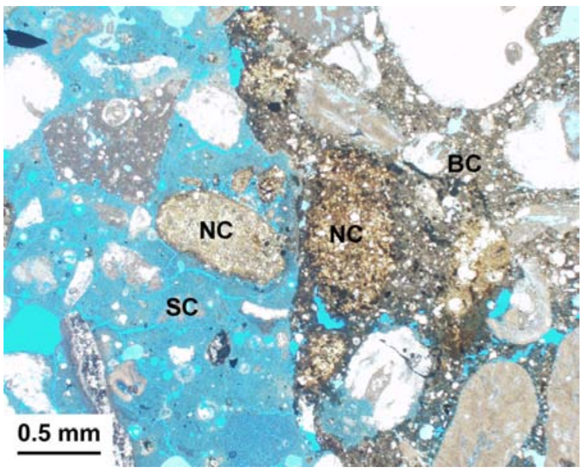
1) The trainee would be taught early on to distinguish artifacts based on optical relief (difference in refractive index). The artifacts such as those observed in Fig. 26 entrain air that has a much lower refractive index than any surrounding feature. It is this extreme relief that tends to preferentially draw the attention of the novice user. An experienced user learns to instinctively ignore these. Refractive index and optical relief represent the first major quantitative properties that form the basis of petrographic data collection. Without a firm foundation in refractometry, it is impossible to use the PLM effectively.
2) Birefringence or the quantitative anisotropy in crystal structure is the second critical tool essential to an understanding of polarized light microscopy. Birefringence presents as visually identifiable interference colors and patterns under crossed polarization and stage rotation. The author fails to notice that the gray interference color is consistent across the "crystal boundaries". The consistent color should indicate that the grain is one crystal rather than a collection of many small crystals.
3) The author does not recognize that the artificially produced microcracks are not structurally consistent with any type of real crystal boundary. Assemblages of quartz crystals would never form in this way and it indicates that the author has insufficient experience in the natural occurrence of geological materials. This is a major barrier to the characterization of historic binders where it is the residual geological textures from the source rocks that are required for positive identification of binder type and provenance. The author states that binder identification is the first goal of the materials analysis (pg. 241).

> "The red colored natural cement relic is similar to those seen by other investigators"

The grain shown by the author in Fig. 26 may be a natural cement relic but it does not exhibit any diagnostic textural features needed to make a positive identification. As discussed above, it is the identification of residual cement rock microstructure that is used to distinguish the calcined binders (i.e., natural cements, hydraulic and non-hydraulic limes). The author seems to be relying only on color and this should never be used as a diagnostic tool. Experience in distinguishing the microtexture of the variety of limestones used to manufacture cement and lime is essential in using the PLM to identify historic binders. In none of the petrographic descriptions or micrographs presented in the remainder of the report does the author provide diagnostic evidence for any of the identifications made.

Finally, the author fails to use the PLM as a verification tool where the interpreted compositional proportions are either unusual or easily distinguished through the qualitative characteristics of the binder. An example is the identification of three different binders in the Battery Huger concrete sample (page 263). The author interprets the concrete as a mixture of portland cement, natural cement, and lime. Anyone having expertise in historic concrete would find this mixture highly unlikely and would seek to demonstrate the validity of the interpretation or at least admit to the singular nature of the mix. The author presents a petrographic image in Fig. 35 but fails to detect portland cement clinker residuals (which should be detectable even where leached), natural cement residuals, or discrete lime particles. A cementitious paste is identified as hydrated portland cement with no justification. It seems that lime carbonate is used to identify lime when this simply may represent local carbonation of a pure cement paste as is characteristic of hydrated and cured natural cement.

On page 262, the author presents his interpretation of the mortar proportions where variations in cement to lime ratios are reported. These are sufficiently lime-rich that it should be a simple matter to see the effects of the lime content on the microstructure of the hydrated binder. For example, Sample 6 is reported to have a cement to lime ratio of 1 : 2.5. At this level, the hardened paste should have characteristics more like that of a lime mortar than a cement mortar. With the low sanding, characteristic lime shrinkage cracks would be found. The brown cementitious hydrate should be sparse and the capillary pore structure dominated by evaporable water loss rather than closure due to formation of hydrated cement. Yet Fig. 27 illustrates a microstructure much more like that of a cement-rich mortar. I have included a photomicrograph below from a project we have worked on previously. The plaster sample consists of a lime-rich scratch coat (SC at left) overlain by a pure natural cement brown coat (BC at right). Natural cement (NC) is present in both though subordinate to lime in the scratch coat. The difference in microstructure should be obvious even to the casual observer. It is these sorts of qualitative verifications that are missing from the analysis.




**6.2 Chemical or Other Analysis to Quantify Proportions**
We have read through the document several times and have failed to find a proper or consistent explanation of how mortar proportions were ultimately determined. There seems to have been a struggle to find an appropriate methodology and some cryptic and incomplete explanation of which parts of the analysis contributed to the final determination. This alone leads to a basic criticism in that there is no reporting of possible errors or uncertainty and no ability for future workers to reproduce the results found. We are forced to take these proportions at face value. The author is not following any standard protocol for composites analysis and the report as provided would not be expected to pass a formal peer review.

Interesting is that the author all but admits that his methods do not work though blames other causes. In Appendix E where the results of an accelerated durability test are presented, the author reports that he measured the compositions for the laboratory prepared mortars (pg. 304). The chemically determined compositions vary widely from the specified mixes. The author suggests poor mixing, small sample sizes, or bad density assumptions in ASTM C 1324 as possible causes for the lack of agreement. We would suggest that improper analytical methodologies are the root cause.

What is unfortunate is that the simplest and most direct procedure available to determine the bulk chemistry of the binder matrix is not employed. Several references are made to ASTM C 1324 for mortar analysis and yet these procedures are almost entirely ignored. These would have required the skill of a professional chemist to effectively use standard wet-chemical analytical chemical methods to bring all of the identified binder into solution for direct measurement through equipment such as atomic absorption spectroscopy. The silicate-rich and acid-insoluble sand should allow for a simple partitioning of the binder fraction into solution for this direct measurement. This is an example of where the choice of equipment and methodology is dictated by the personnel and machinery available to *this particular laboratory* and not by the best choice of methods generally available for the questions being asked. Had the author followed the correct procedure, there would have been a weight percentage of sand, weight percentage of ignition losses (water and carbon dioxide), and weight percentage of the elemental components of the binder alone. The first two are determined but the third is either ignored or at best questionably estimated through unnecessarily indirect methods such as EDAX or reverse calculations from low accuracy TGA methods.

Table 16 on page 250 appears to represent one attempt at binder chemistry determination. The table presents irrelevant data including the *bulk* chemistry of the mortar (upper portion of the table) and the bulk chemistry of sand extracted through acid digestion (lower portion of the table). The bulk mortar chemistry would tell us nothing since the signal is overwhelmed by the sand chemistry. The sand chemistry itself serves no useful purpose as it tells us nothing about the mortar properties. Simple mineralogical description and particle texture characteristics determined through petrography is usually all that is needed for the aggregate. The format of the table suggests that the author wants to subtract the sand (normalized to its insoluble residue weight percentage) from the total mortar chemistry to determine the binder chemistry. The fact that the same sand value is repeated two or three times further suggests this intent. As a side note, the identical sand chemistries presented for Samples 5, 6, and 11 are impossible and should not be misrepresented as measured data as is implied by their appearance in the table.

The sort of difference calculation suggested here is subject to very large errors. Essentially, a small error in a large number (the sand weight) magnifies to a large error in a small number ($SiO_2$ weight in the cement). As our Fort Jefferson report is referenced in this HSR, we should admit that our lab was forced to perform a similar calculation for the mortars at Fort Jefferson since the coral sand there is completely soluble in the acids used in the analysis. However, this was done out of necessity and several factors allowed us to develop confidence in the approach for these particular samples. Firstly, petrography showed that only natural cement and coral sand were present. There was no lime to have to proportion mathematically with the cement. Secondly, no $SiO_2$ and very little MgO was contributed by the sand meaning that we could consider these components and ignore CaO for an assessment of the binder. Thirdly, we were able to extract rather large cement lumps for direct measurement of the binder chemistry itself and present this as typical. Finally and most importantly, we relied on micrometric point-count analysis as an independent method to demonstrate cement to sand proportions and cross-check our less certain chemical interpretations.

In the case of the Fort Sumter mortars, the subtraction method is not necessary at all since the sand is not acid-soluble. As an exercise, we completed the calculations suggested by this table for Sample 11 to assess possible errors assuming this was what was intended. If one assumes a standard analytical error of ±2% in the insoluble residue value, this would result in a ±27% error in the resulting $SiO_2$ value once the sand chemistry is subtracted from the bulk mortar chemistry. As the $SiO_2$ is primarily used to calculate cementitious components, the methods would lead to almost ±30% uncertainty in the calculated cement content. This does not take into account the compounding of other standard errors such as those related to the silica measurement itself. Ultimately, if this type of calculation scheme is not to be used, we are left wondering about the purpose of including this table in the report at all. It is not used for anything else later and the data provide no insight into the existing mortar characteristics.

On page 253, there is a new section that in the Table of Contents is described as a Special Case Study of Sample 30. To some degree, it seems that this is meant to represent an example of how one mortar is analyzed for composition. Even here, we could not find a coherent description of a systematic analytical approach but rather a collection of data with no explicit interpretation. The table on page 255 is especially bizarre. It is reported to represent matrix chemistry and it is here that we thought we might find the subtraction method being used to determine the binder chemistry. However, the first part of the table turns out to be a strange circular calculation that goes nowhere. Close inspection illustrates that the "Mortar Analysis" column is simply taken from the bulk mortar XRF data presented on page 258. The original values are normalized up to near 100%. This column only represents the total mortar chemistry including both binder and sand. The second column simply takes the same numbers and normalizes them downward by the sand weight. In essence, these numbers are proportionally the same but for some reason the total mortar chemistry is related to the sand weight. Then the "Difference" column takes the normalized or proportionally shrunken numbers and subtracts them from the original numbers. So these numbers are yet again proportionally the same. Finally, the difference is normalized back to 100% to represent the matrix chemistry. In fact, these are the same exact numbers that the author started with and the small differences are due either to rounding error or the small normalization difference between 98.64 and 100.01. The first portion is nothing more than the total mortar chemistry (sand included) divided, subtracted, and multiplied by itself in a completely meaningless and circular manner. The final column is not the matrix chemistry but rather the total mortar chemistry.

The next part of the table presents historical cement data presented in three different ways. The author has a conclusion at the top of the table indicating that the analysis suggests Rosendale cement based on similarity in chemical ratios with the historical data. Firstly, ignoring whether this is true or not, the ratios chosen would normally be the least robust to use for this type of comparison. Secondly, if we mistakenly believe that the calculated matrix chemistry represents the binder (which it does not), the ratios the author reports as matching do not in fact match. Finally and most importantly, the binder chemistry is not determined from this circular argument so any attempt at comparison is meaningless.

Finally, only a single sentence is found on page 262 representing the only description of the methodology used to calculate the original proportions. This suggests a determination of sand through insoluble residue, the lime through TG/DSC, and the cement through EDAX. We can only agree with the first measurement as representative of the sand. However, the DSC data cannot be used to calculate a lime component in the manner the author hopes. This method at best can be used to determine the relative abundance of components that decompose at high temperature such as hydroxides or carbonates. To assume that all hydroxide derives from the lime ignores the fact that natural cement contains calcium hydroxide originally and portland cement creates it as a product of hydration. Any attempt to partition a lime component from these data would tend to overestimate lime species. This is an oversimplified argument as there are many other accuracy issues that could produce significant uncertainty in either direction. However, it can be argued that even a pure natural cement mortar would produce a signal using DSC that would be misinterpreted here as lime.

Using EDAX to produce a cement chemistry that can be used to estimate proportions is incorrect. The technique measures chemistry at the submicroscopic level thus sampling unrepresentative areas of the binder. The mineralogical variation in natural cement is significantly coarser-grained and it is necessary to sample large areas to produce an accurate representation of the composition. An example of where this method goes wrong can be found in the EDAX table on page 248. Column 3 is an EDAX signal from a cement agglomerate though the silica content is about a tenth that of calcium oxide. Calculation of a cementation index (variation of a lime saturation index) results in a value of 0.3 and this would be typical of a hydraulic lime. In contrast, the lime agglomerate in Column 5 has a chemistry that is more cementitious than that of the natural cement agglomerate. A cementation index of 1.0 is characteristic of portland cement and some natural cements. If this is the type of analysis used to estimate the cement content then it must be assumed that the batch formulas in Table 21 are erroneous.

**7. Emphasis on Technical Data**

The authors appear to have limited prior experience in historical masonry though it is apparent that there has been a wealth of technical reading on the subject during the preparation of the document (Appendix F). This causes the authors to underestimate practical considerations in masonry construction, mortar design, and placement and instead overemphasize technical matters. There is a general neglect of important features such as sand gradation, placement and consolidation, and mix water contents. Some examples:

Sand texture and gradation are important mortar features as they affect workability, placeability, larger scale porosity, and ultimately bond capacity. In Appendix B, there is an opportunity to discuss these more fundamental properties petrographically but this is neglected. Instead, the author measures the sand's elemental chemistry through X-ray fluorescence (XRF). The resulting chemical data provides no useful information about the aggregate and how it might have affected the original performance characteristics of the mortars. Sidelining of the sand gradation also appears later in the document. The author includes the importance of sand gradations within a bulleted list of criticisms of NPS Preservation Brief No. 2 (Appendix K, page 386). Though it is not stated explicitly, the reader wonders if the author is disagreeing with this importance. In Appendix I (pg. 375), the author presents a table listing what he considers to be important mortar properties. Technical features such as vapor permeance and minimum compressive strength are considered essential while the more basic sand gradations that bear on those features are considered merely useful.

Porosity is emphasized in Appendix B through the use of numerical data derived from mercury intrusion porosimetry. However, there is virtually no discussion of the possible everyday sources of porosity variation. Is the measured porosity related to capillary pores, air-voids, consolidation voids, shrinkage cracks, and/or water voids and how do they relate to the original design and placement of the mortar? These could have been assessed petrographically to provide evidence of the original mixing and placement methodologies and by extension the possible performance characteristics of the material. There is only one explicit description of pore structure on page 268 (Fig. 39). The author includes this along with the rubble concrete though the micrograph seems to show an image of the parging. Nonetheless, the author shows an image of what appears to be consolidation voids presumably caused by a dry mixed cement, narrow sand gradation, and/or poor

consolidation during placement. Instead of considering simple mix and placement related features, the author appeals to an interpretation that requires corrosion of the binder by salt intrusion and chemical reaction neglecting the fact that salt corrosion does not produce the types of pores shown. As a side note, Fig. 37 of the rubble concrete is identified as a lime concrete where the matrix is apparently cementitious. Mixing of cement rather than lime with a low water content is a common cause of the type of pore structure shown in Fig. 39.

**8. Speculation and Selective Interpretation**

The organization of the report makes it difficult for the reader to assess the quality of the various conclusions. There is a linear stream of data and interpretation for each material and test with sporadic notes on pieces of data that support one concept or another. It is not clear if this is caused by the short time available to reorganize the text once a first draft was written. Data sections listed as "In Progress" (pg. 258) would seem to suggest this. However, when the narrative is carefully studied, there is an uncomfortable amount of "cherry-picking" of small pieces of data to support an interpretation. In itself, there is nothing wrong with speculating on interesting pieces of data. However, there is a sense that most of the conclusions are based largely on these sorts of narrow speculations with few pieces of conclusive evidence. Many examples of these speculations follow:

- (pg. 209) The interpretation is not clear though there is an insinuation that the relative concentration of salts detected from tape lifts along the scarp wall indicates leaching from the constituent materials. Calcium and sulfate enrichment relative to chloride in "typical" seawater are attributed to the binder yet there is no explanation for a similar sodium enrichment where there is no expectation of the element from the binder. The comparison to what is considered to be normal seawater is not nearly enough proof for the implied mechanisms and insufficient qualification and uncertainty is expressed by the author.
- (pg. 212) The author states that evidence is shown in the report for the solution of lime from mortar species. We have not been able to find any unequivocal evidence presented to support this claim. Similarly, the author states that microscopic evidence for gypsum in brick cracks will be presented and there is no such evidence presented.
- (pg. 213) We have to trust the author that the needles shown in the SEM image are in fact ettringite. This aside, the statement that ettringite is usually accompanied by expansions is misleading. Ettringite is ubiquitous in older mortars and is only related to expansion when it forms in situ within the cement paste due to metastable sulfate rather than precipitated passively due to pore water concentrations.
- (pg. 219) The author wants to illustrate the permeability of the brick and mortar and as evidence shows an air-void in mortar in Fig. 8. The air-voids are responsible for the porosity of the mortar but it is the finer capillary pores (not illustrated or considered anywhere in the report) that are responsible for the permeability.
- (pg. 228) The author is comparing brick data form specimen to specimen. Assuming that a standard deviation for the same source of brick might measure in 10's of percent of the average, the suggestion that chert content explains differences in absorption and saturation coefficient between the two brick "types" is completely speculative.
- (pp. 228 - 230) As far as can be seen, two brick specimens were measured for thermal expansion. In the last bullet point on pg. 228, it is simply assumed that the thermal expansion of the first four families is likely to be very high though no data is offered. Yet, the author is somehow comfortable suggesting that one could expect unusual differential stress in the wall based only on two measurements.
- (pg. 243) The author uses the MIP data indicating fine pores to support an interpretation of binder corrosion due to seawater infiltration. The author completely ignores the more important influences of original water/cement ratio or lime content on the fine pore structure.
- (pg. 245) There is a cavalier statement that experience shows that appropriate repair mortars should have a vapor permeance greater than 2.5 $mg/s \cdot m^2 \cdot Pa$ after a 30 day cure. A casual read might suggest that this opinion is based on the data presented just above. Yet, there is no obvious support offered for this statement.
- (pg. 247) In Fig. 28, the author is illustrating an opaque phase and identifies this is as apparent evidence for corrosion of the lime phase. Corrosion of lime is not expected to produce anything opaque in plane light. This must be an entirely different material included in the mortar matrix where lime or carbonate was never present.

- (pg. 262) The author states that all mortars contain Rosendale natural cement. However, there is no positive evidence offered to discount other sources of American natural cement.
- (pp. 263-264) The concrete at Battery Huger is quite probably a natural cement concrete based on the texture of the paste shown in Fig. 35. The typical patchy carbonate and cementitious hydrate structure is instead interpreted as a combination of lime and portland cement respectively. For some reason, the typical natural cement color is attributed to what is called a sufficient iron oxide content in the portland cement. This is an unsupported statement used to explain a possibly erroneous identification.
- (pp. 266-268) There is a desire to find evidence for deleterious salt distress everywhere throughout the report. No physical evidence for salt distress is presented for the rubble concrete but small insignificant bits of data are insinuated to be related to such distress. A pore is shown in Fig. 37 with a ring of carbonate. This is quite common in many older mortars including those that have never been subject to salt distress. Halite and calcium chloride are identified by XRD and of course these do indicate evidence of salt exposure. However, they do not demonstrate damage due to salt distress. In Fig. 39, pores created by what appears to be poor consolidation of a possibly dry mix with poorly graded sand is offered as evidence for salt corrosion.
- (pg. 271) The author presents a soluble salt analysis of the infill soil and suggests that the content is sufficient to cause cryptofflorescence in bricks. However, there is no indication of which salts and at which level are of concern. In fact, the salt content appears surprisingly low given the proximity to sea water.
- (pg. 273) A completely speculative interpretation is offered on environmental effects on the sandstone. The existing pore space that is more likely a feature of the original sandstone is suggested to have been caused by moisture moving throughout the material. The presence of high potassium in the pores is attributed to degradation of the sandstone despite the fact that few of the identified mineralogical constituents contain potassium. The albite which might contain small amounts of potassium would be much more likely to give up sodium preferentially to potassium and yet the sodium salts are lower than the potassium salts. The presence of calcium and sulfate are suggested as classical “case-hardening” phases yet there is no petrographic evidence offered for this. Finally, an oddly placed sentence regarding consolidants is inserted almost to suggest that this material would be a good candidate for consolidation without any discussion of potential problems with consolidation.
- (pg. 274) Ettringite and thaumasite are identified through XRD as the product of chemical reaction between lime and sea water despite the fact that no such reaction can produce the phases identified.
- (pg. 277) Though it is shown earlier that the local sands are basically typical quartz aggregates found in almost every sedimentary environment, the author attributes the lack of ASR reaction to what is supposed to be a unique mineralogy. The author goes on to identify tridymite, one of the most notorious aggregate types responsible for ASR reaction as the very mineral responsible for the resistance to this reaction. Implicit in this argument is the misconception that ASR is almost guaranteed in the presence of salt water. Ignored is the fact that ASR is not only inhibited in carbonated mortars with lower pH but also rarely occurs in mortars at all due to pessimum effects.

## 9. Accelerated Durability Tests (Appendix E)

The inclusion of this testing program in the HSR is questionable. There is an implication that this type of testing will be used to make critical decisions at the fort and this is concerning due to a lack of control of critical variables such as mix water content. The work is not vetted through the peer review process. Though our lab does not engage in mortar durability tests, we have plenty of experience in mixing mortars for performance testing. We have also been privy to long term mortar evaluations performed by Mr. Norman Weiss at Integrated Conservation Resources. While there are others that might be better choices for peer reviewers, we can certainly raise some points that might be expected from a formal review and these are presented in brief below. Ultimately, it is our opinion that the testing protocol is not well planned and valid interpretations are hindered by a lack of control of the critical variables.

- Up front, the author indicates that similar wear processes would be expected for bricks. The question has to be asked whether more durable mortars under this testing protocol might not be expected to redirect salts into the masonry units themselves. What type of performance is desirable and how to we balance mortar durability against preservation of the brick fabric?

- As discussed earlier in this document review, there is an overemphasis of technical theory at the expense of important practical masonry considerations. In this case, original water contents and mortar consistency is uncontrolled and unreported. Water contents directly affect permeability, cohesive strength, and durability. There is no attempt at standardizing the mixes either through constant water/binder ratio or through control of consistency as determined by either a measurable flow test or plunger penetration test. This would be the first logical step to ensure that the mortars can be compared to one another. It can be argued that test mortars with higher water content would be less durable all else being equal. The ranking presented later may be critically dependent on this important unknown factor.
- Similarly, the curing protocol is not thoroughly considered by the author. A typical initial moist cure for the cementitious mortars is neglected for the cementitious mortars. A high carbon dioxide environment is used to accelerate carbonation. However, it is not considered that a saturated $CO_2$ environment as opposed to a natural environment may actually be corrosive in itself. Instead of checking carbonation and adequacy of cure directly through application of pH indicator (a very visual and easy to interpret method), the author relies on indirect measurement through TGA. The methodology is overly technical and introduces unnecessary error. The entire curing period lasts only two weeks and is almost certainly insufficient.
- The choice of immersion solutions is questionable considering these are meant to simulate conditions at Fort Sumter. Oddly, deionized water is described as a control solution when this is in fact a corrosive solution for mortar. Hydrochloric acid is fully dissociative and would be rapidly neutralized. Is the acid refreshed regularly? What is this meant to simulate? Why was sulfurous acid (mimicking acid rain) not used instead?
- We raised the point earlier that the author finds poor agreement between chemical analysis of the test mortars and the specified mix. Honestly, we feel that this is a result of poor analytical procedures. However, the author blames mortar homogeneity. If this were the problem, can we trust any of the findings? As a side note, mix 10 is described as “Likely Portland”. Since these are newly prepared mortars and not samples taken from the construction, what does this mean?
- Diametric expansion is used as an indication of failure. How do we separate this from normal volume changes expected during early mortar curing?

**10. Guide for Conservation Mortars (Appendix K)**

This appendix is overly opinionated and in many cases misinformed and reads as a surprisingly brash conclusion to the entire HSR. Though it is likely that the primary workers on the HSR are quite experienced in their respective disciplines, none appear to have much prior experience in historic masonry. The writer is a little too eager to criticize existing norms but does not offer practical solutions based on actual experience. Some specific criticisms follow:

- The first section is simply a criticism of NPS Preservation Brief No. 2. Is it really the role of the Fort Sumter HSR team to criticize the National Park Service in a document meant to be publicly available?
- In the next section, the author presents a Platonic dialogue with the Department of the Interior Standards to create defense for his interpretation. I should be clear that we do not disagree that replication in-kind with natural cement might be an appropriate strategy. However, the author seems to defend this by confusing the concept of preservation of extant fabric with the placement of new repair materials.
- The author mandates the use of Rosendale natural cement in the “Method for Specifying Mortar Mix”. Is this meant to refer to Rosendale brand natural cement or natural cement manufactured from rock mined in Rosendale? Why are other American natural cements disallowed? Only ASTM C 144 compliant sand gradations are allowed. Many historic mortars are mixed with non-compliant sands often with excellent results. Does the author actually expect every replication mix to meet the properties specified? For example, are we expected to perform Mercury Intrusion Porosimetry for all proposed replication mixes? What is the basis for all of these decisions? Everything in the last column of Table 37 is based on the author’s own proprietary testing much of which is unusual and generally impractical. Again, the practical side of masonry rehabilitation is underemphasized.
- The remainder of the document is based on the questionable findings in the technical sections of this report and not on a general understanding of the field. An example is the questionable identification of lime in the Fort Sumter mortars.