A Report on the Structural Issues at

Fort Sumter National Monument

Charleston, South Carolina

4SE Inc.

Wednesday, July 8, 2009

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Introduction

In December of 2008, Rick Dorrance of the National Park Service asked Craig Bennett of 4SE, Inc. to conduct a brief structural inspection of Fort Sumter National Monument and to provide a brief report focused not on findings but on conclusions and recommendations. This report was not intended to thoroughly document current conditions of the fort; instead, its purpose was to point out areas which would need attention to ensure the long term future of the fort.

This report, the result of that inspection, discusses areas of structural distress and proposes several ways to further study these areas of concern in order to ascertain their magnitude and develop appropriate mitigation techniques. In doing so, this report will act as an aid to the National Park Service in determining a strategy for protecting both the fort and its many visitors.

The report is based on the findings of one recent site visit combined with a study of architectural drawings and a review of several recent reports. The on-site inspection was limited to visual observations of the interior and exterior of the fort. The recommendations included in this report address several methods for further investigation which will be necessary to determine the structural integrity of Fort Sumter. Once the full extent of damage is understood, appropriate mitigation strategies can be implemented. In a few instances, this report also discusses the need for immediate repairs. These particular recommendations address visible damage that could threaten the safety of Fort Sumter's employees and visitors.

Several documents were provided by the National Park Service. While these documents were of help in understanding several of the most recent studies of Fort Sumter, the limited scope of this report did not permit a thorough and detailed study of each document. The documents provided include:

- Selected architectural drawings (1845-1991)
- Settlement Survey, Michael Shulse, PLS (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)

Description

Construction of Fort Sumter began in 1829. The fort is a pentagonal brick structure on a foundation of granite set on a sand bar at the entrance of Charleston Harbor. 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, a concrete bunker on the interior of the fort, was added during the Spanish-American War. Because of its important role in our nation's history, Fort Sumter became a National Monument in 1948. A complete history can be found in the National Park Service archives and at the Library of Congress.

Fort Sumter is an example of the design and construction typical of Third System coastal defenses (Fig. 1-2). The rampart consists of several elements. The first, a thick scarp wall, forms the perimeter of the fort. Embrasures (many now bricked in or covered) were built into the scarp to allow cannons 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 was originally vaulted, with the vaults resting on arched abutments that extend from the centers of the arcade piers. As shown in Figure 1, the arcades, vaults, and scarp are not tied together, but are in fact separate systems. However, loads are transferred between the structural systems through direct contact.

When Fort Sumter was partially rebuilt in the 1870s, the upper casemates were eliminated (Fig. 1). The casemates along the Right Face and Right Flank were covered with earthen 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.

Findings

At the request of Rick Dorrance of the National Park Service, Craig M. Bennett, Jr, P.E. and Hillary King of 4SE, Inc. conducted a visual inspection of Fort Sumter on March 20, 2009. The purpose of this site visit was to provide an initial look at the structural integrity of the fort in order to establish the value of additional studies and repairs. Specifically, 4SE was 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 determine conditions and requisite repairs for long term stability.

During this site visit, both the interior and exterior walls of the fort were inspected. The exterior examination was conducted at low tide to maximize visibility of potential structural concerns and damage to the façade surface. The interior examination was focused on the vaulted arcades along the perimeter walls. Battery Huger was not included in this assessment.

The exterior walls revealed several categories of damage:

- Superficial damage, including surface erosion of bricks, mortar, and concrete
- Bowing out of walls as they approached each corner of the fort
- Masonry cracks

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 (Fig. 3). Erosion is worst where granite revetment blocks rest against the wall (Fig. 4). Above the high water mark, erosion of the face of the wall was most severe on the Salient, Right Face, and Right Flank which face the shipping channel (Fig. 5-6). In some locations, previous repointing with Portland cement has helped to accelerate the loss of the brick face (Fig. 7). Loose bricks along the cornice were also noted along the exterior (Fig. 8).

To varying degrees, it appears that the long walls of the fort bow outwards as they approach the shoulders, gorges, and Salient. This is clearly discernible in Figures 9 through 12. If the wall were in plane, the mortar lines could be traced along a straight line. 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 seemed to be focused towards the ends of the long walls and on the shoulders (Fig. 13-18). Several of these cracks extended from the top of the wall to below the revetment. Others started at the top of the wall and stopped at a corner before reaching the base of the wall. The Right Face and Right Flank contained the majority of the cracks noted on this site visit.

Inside the fort, much of the visible damage consisted of cracked arches and vaults. A number of arches in the arcades are cracked, especially at the ends of each arcade (Fig. 19-20). Many of vault-supporting arches are also cracked; both vertical and horizontal cracks were found in a significant number of these arches (Fig. 21-22). Some of the abutments also showed signs of movement (Fig. 23).

Each of the casement vaults that were examined as a part of this site visit has a crack running perpendicular to its axis (Fig. 21-22, 24-25). The cracks are of varying sizes, and fluctuate in location slightly, but tend to be close to the center of the span 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 (Fig. 26). Many of the cracks in the vaults have been filled with epoxy and/or mortar (Fig. 24-25). In some locations, the filled crack has reopened or a new crack has formed adjacent to the repair (Fig. 25).

Other cracks can be found throughout the fort with varying causes (Fig. 27-28). These should be evaluated individually to determine overall stability of the fort and to establish whether the damage represents any broad themes of structural distress.

Also noted during the course of this inspection were two issues that present safety concerns. Loose bricks along the edges of broken vaults, arches, and the cornice could fall, injuring a visitor or employee (Fig. 8, 29). Also, severe cracks in the concrete over the cistern near the Left Face indicate that there is the possibility of localized catastrophic failure (Fig. 30). Visitors are currently allowed to walk over and stand on this cistern.

Conclusions

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 was too strong has accelerated the erosion of the face of the brick (Fig. 7). In other places, mortar that was too soft has disintegrated, leaving large holes between bricks, compromising the structural integrity of the outer skin of bricks and allowing water behind it (Fig. 6).

Severe erosion has also occurred at the base of the wall, where continued exposure to water has eroded the mortar (Fig. 3). In locations where the granite blocks of the revetment touch the brick wall, erosion has been accelerated (Fig. 4). The granite affects the flow of water around the stone, causing excess friction against the brick wall. Mechanical erosion caused by small movements of the blocks as the tide flows in and out could also contribute 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.

The bowing of the walls visible on the exterior of the fort 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 each of the fort's shoulders, the thrust is not adequately counteracted, and therefore pushes the walls outward and breaks the arches near the ends. 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 (Fig. 31-32) may cause damage through differential expansion, as these sections would behave slightly differently than 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 a lack of support: it appears that the piers, abutments, and perimeter walls do not adequately resist thrust. 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 23. This arch is broken in two locations,

indicating that the thrust is not being adequately resisted by either of the abutments. 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 recorded in the vaults may result from the movement of supports, causing the vaults to act as a beam between the inner and outer arcades rather than transferring load to the single arches at each end of the vaults as designed. Other possible causes include differential settlement or differential expansion of the bricks.

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. The cistern also shows signs of failure and potential collapse.

Recommendations

Of utmost concern are any elements that compromise life safety at the fort. We recommend that all bricks held in place only by tension stress in the mortar be checked for a tight bond to the substrate. All loose bricks should be carefully removed and stored for use in future repair work. Any cracks through the cornice or around single or small groups of bricks should be monitored for loosening. We also recommend that the cistern near the Left Face be blocked off so that visitors cannot stand on the concrete in that area until it has been examined and either deemed safe or repaired.

Mortar repointing and replacement of severely deteriorated or missing bricks should be conducted along the exterior wall. Granite blocks along the revetment that touch the exterior wall and increase erosion of the bricks 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.

Given the limited scope of this report, we are not prepared to make a recommendation on the removal of the revetment. Significantly more study will need to be completed before any conclusions can be drawn or various strategies can be considered.

Further studies are also recommended before deciding on a treatment approach to correct structural problems present in the rampart, foundations, cisterns, and Battery Huger. Given Fort Sumter's

location in Charleston Harbor and current conditions like the presence of the revetment and earthen fill, careful planning will be required to generate the best information from additional studies. We recommend that a full laser scan of Fort Sumter be conducted. The scan should include the interior, exterior, and several cross sections through the rampart. This will provide valuable information about the construction and current conditions of the fort that would be very difficult to obtain by other methods. Several sections of the scarp wall will need to be scanned from a barge, spudded to prevent movement. The information provided by this work will aid in determining how much the scarp is leaning or bowing out of plane, and this will guide the structural evaluation, modeling, and analysis.

As granite blocks are moved for exterior repairs, we advocate that a closer inspection of the foundation be conducted by structural and geotechnical engineers. Currently, it is impossible to determine the condition of the foundation. If settlement issues or problems along the exterior are found, excavating select areas of the foundation may be necessary. A study conducted by a geotechnical engineer will show whether or not the foundation and soils are able to continue to hold the fort without additional support.

In order to adequately analyze the structural integrity of Fort Sumter, an in-depth conditions assessment should be undertaken, noting the locations and severity of all interior and exterior cracks, bowing, and other damage. Cracks and other conditions should be monitored and any changes examined for indications of structural distress. Combined with the laser scan, this evaluation will provide the information required for linear and non-linear structural modeling and analysis. We suggest the development of three planar models: a section perpendicular to the rampart, a section parallel to the scarp wall, and a third model 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 3D structural model could be created to generate a more complete picture of structural stresses. We suggest 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, and half of the Right Flank. The 3D 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 where and how much intervention is necessary to prevent further damage to or loss of historic material.

In addition, we recommend that structural assessments of the cisterns and of Battery Huger be conducted as a part of these studies. Each should be assessed for structural integrity through on site observations and analysis of visible deterioration. Materials testing would be beneficial in determining the conditions present in the concrete and ferrous structural elements of Battery Huger. Based on the structural assessments, repairs would be suggested to insure that these elements of the fort will pose no danger to employees or visitors.

Finally, we recommend that a settlement survey of the fort, similar to those conducted in 1992 and 2006, be repeated during the course of this phase of study. However, we do not suggest reusing the old base point for these surveys, which was located within the fort. Using that point only allows the surveys to illustrate differential settlement, and cannot show settlement as a whole. Based on structural drawings of the new pier, it appears that the piles extend down to marl, making the structure stable and therefore a satisfactory base point from which to conduct future settlement surveys.

Each of the recommended studies discussed above would contribute valuable information about Fort Sumter's structural integrity. This information is integral for determining proper treatment and repairs for this National Monument. Suggesting repairs without further studies like those discussed in this report is tantamount to a guess and may or may not be beneficial to the fort's continued use.

Submittal

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.

We appreciate the opportunity to present this report to the National Park Service. We look forward to helping move the project ahead.

Sincerely,

Hillary N. King, Conservator
4SE, Inc.

Craig M. Bennett Jr., PE
4SE, Inc.

Appendix A
Estimated Costs for Further Studies

The following information includes what we believe to be the approximate costs of performing the engineering studies mentioned in this report. Various elements of these studies would be performed by surveyors, geotechnical engineers, structural analysts, and structural engineers specializing in historic preservation. The work should be coordinated by an engineer or another individual or firm qualified to interpret the results as a whole.

Laser scanning of interior and exterior of Fort Sumter: This is work which would be performed by surveyors having particular expertise in laser scanning and interpretation of the output. We have worked with three surveyors who have done this work for us in the past and find that the surveyors out of Miami who have done the work at Fort Jefferson, Dry Tortugas appear to be better positioned than most to do this.

• Travel expenses	$ 4,000
• Barge, spudded for stable scanning point	$ 8,000
• Scan of exterior, including sections through rampart	$ 15,000
• Scan of interior	$ 3,000
Total:	**$ 30,000**

Revetment, foundation, and geotechnical work: This work is best done by local geotechnical engineers with input into the process and additional interpretation of the results by geotechnical engineers who have significant experience in historic structures.

• Move select revetment blocks	$ 5,000
• Foundation structural inspection	$ 3,000
• Geotechnical analysis and report	$ 10,000
Total:	**$ 18,000**

Structural assessment and analysis: In this case, the conditions assessment is best done by an engineer, as it is specifically intended to glean information about the structural performance of Fort Sumter. Using the information from this assessment, the planar analysis work should be completed by engineers with particular expertise in the analysis of unreinforced masonry structures. However, the 3D, non-linear analysis, which will reveal important information about the structural performance of the fort, requires specialized software and expertise and is best left to structural analysts specializing in this particular type of modeling. These analysts would work with the engineers who have completed the assessment and planar analysis to achieve the most useful results.

• Comprehensive conditions assessment	$ 6,000
• Planar modeling analyses	
-Perpendicular to rampart	$ 7,000
-Parallel to rampart	$ 9,000
-Earthen fill along Right Flank	$ 12,000
• 3D analysis of Right Face, Salient, half of Left Face, half of Right Flank	$ 45,000
• Cisterns	
-Evaluation	$ 1,500
-Analysis	$ 6,500
-Repair drawings	$ 3,000
• Battery Huger	
-Evaluation	$ 5,000
-Materials Testing	$ 3,000
-Repair drawings	$ 7,000
Total:	**$105,000**

Settlement survey: Settlement surveys, generally done by local surveyors working under the direction of a preservation engineer, provide the owner with clear information on the long term vertical movement of the structure.

• Installation of new survey points	$ 3,000
• Initial Survey	$ 8,000
Total:	**$ 11,000**

Appendix B
Figures

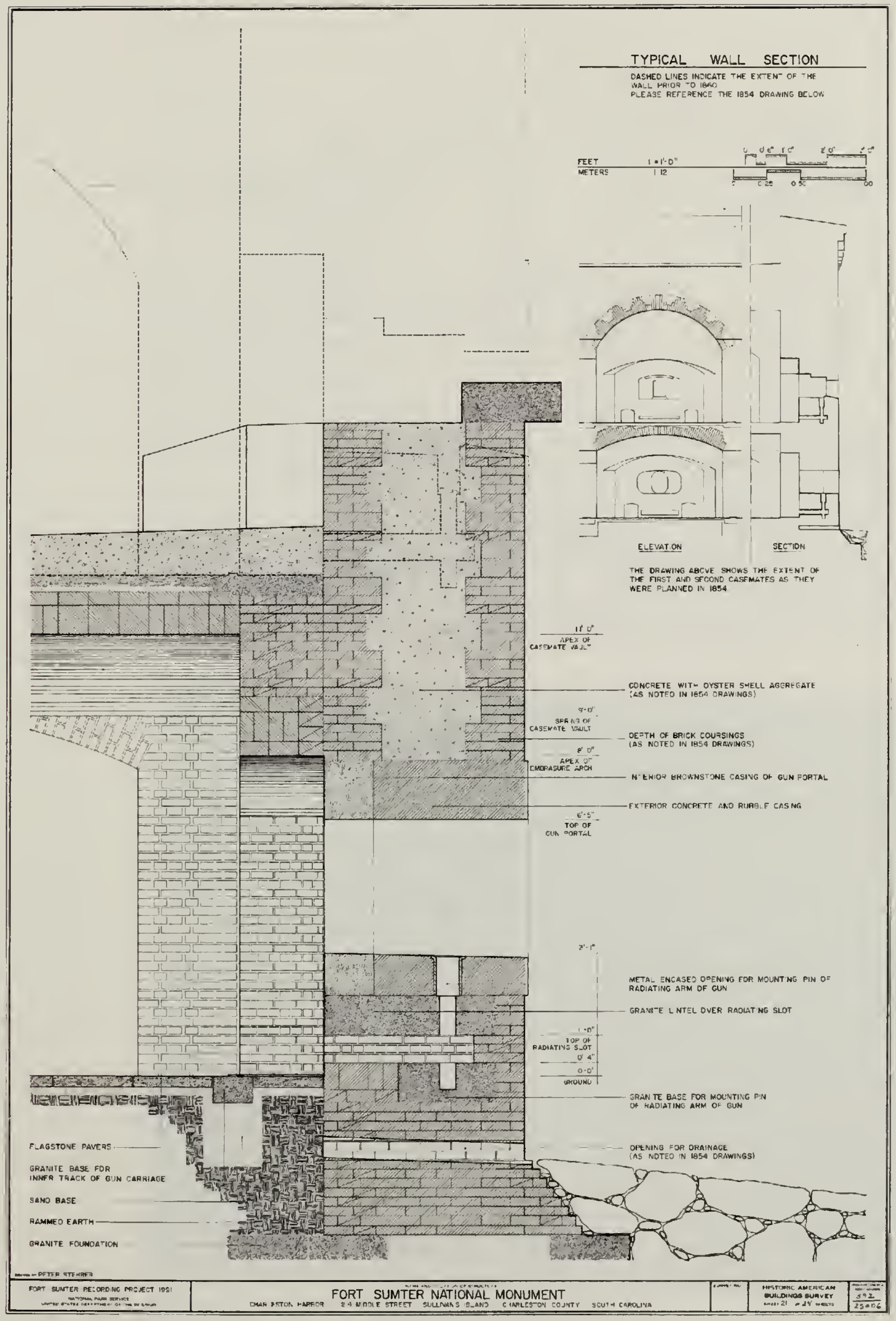

FIGURE 1: Fort Sumter Recording Project, HABS, 1991

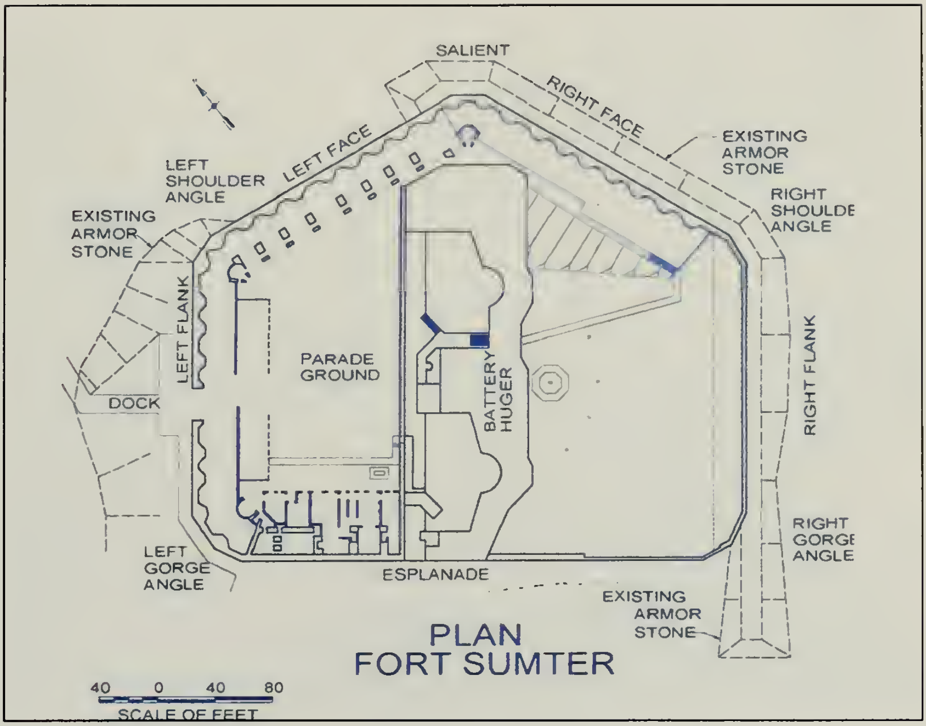

FIGURE 2: Plan of Fort Sumter, Armor Stone and Outer Wall Structural Study, 1998

FIGURE 3: Erosion of mortar below high water mark, Left Face, March 2009

FIGURE 4: Accelerated erosion around granite blocks, Right Face, March 2009

FIGURE 5: Erosion of wall surface, Right Face, March 2009

FIGURE 6: Erosion of wall surface and mortar, Right Face, March 2009

FIGURE 7: Portland cement used for repointing, Right Flank, March 2009

FIGURE 8: Loose section of parapet/cornice, Left Flank, March 2009

FIGURE 9: Bowing, Left Face, March 2009

FIGURE 10: Bowing, Right Flank, March 2009

FIGURE 11: Bowing, Gorge Wall, March 2009

FIGURE 12: Bowing, Left Flank, March 2009

FIGURE 13: Masonry cracks, Right Face at Salient, March 2009

FIGURE 14: Masonry crack, Right Flank, March 2009

FIGURE 15: Masonry crack, Right Flank at Right Gorge, March 2009

FIGURE 16: Masonry crack, Right Flank, March 2009

FIGURE 17: Masonry crack, Gorge Wall and Right Gorge, March 2009

FIGURE 18: Masonry crack, Right Gorge and Right Face, March 2009

FIGURE 19: Cracks through arch, Right Face arcade, March 2009

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

FIGURE 21: Crack running through vault and supporting arch, Right Face, March 2009

FIGURE 22: Crack extending through vaults and supporting arches, Right Face, March 2009

FIGURE 23: Several cracks are visible on this supporting arch at the Salient, March 2009

FIGURE 24: The crack in this vault has been repaired with epoxy, Left Flank, March 2009

FIGURE 25: The crack in this vault has been covered with concrete, but that patch has also cracked, Left Shoulder, March 2009

FIGURE 26: This vault has cracked in both directions, Right Face, March 2009

FIGURE 27: Cracks caused by internal pipe, Right Face, March 2009

FIGURE 28: Crack through corner of arch, Right Face, March 2009

FIGURE 29: Loose bricks inside fort, Left Face, March 2009

FIGURE 30: Cistern, March 2009

FIGURE 31: Original and rebuilt sections of the Right Gorge, March 2009

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

Appendix C
July 9, 2009 Presentation


Fort Sumter National Monument
Structural Report
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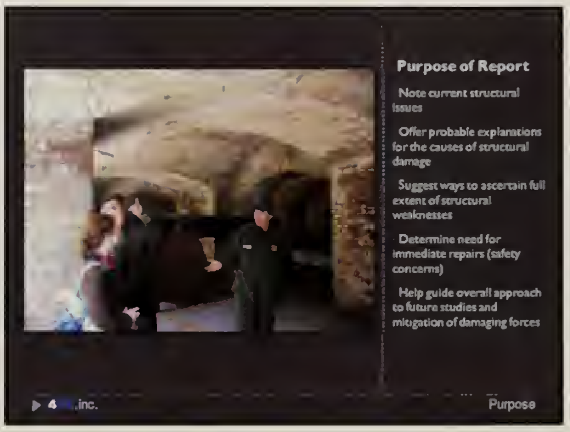
July 2009


Purpose of Report
Note current structural issues
Offer probable explanations for the causes of structural damage
Suggest ways to ascertain full extent of structural weaknesses
Determine need for immediate repairs (safety concerns)
Help guide overall approach to future studies and mitigation of damaging forces
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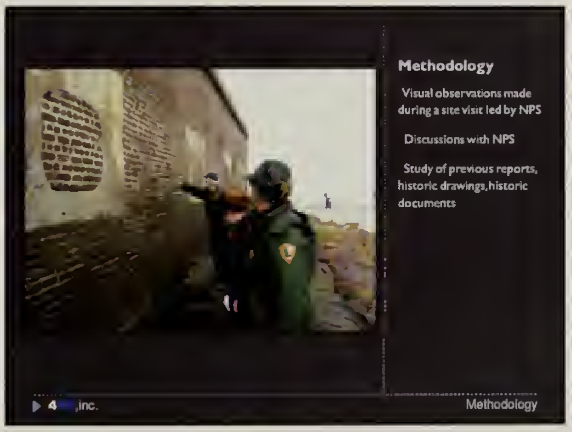
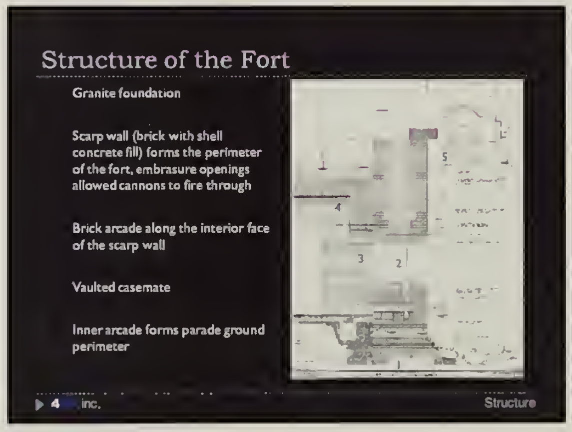
Purpose


Methodology
Visual observations made during a site visit led by NPS
Discussions with NPS
Study of previous reports, historic drawings, historic documents
4 ,inc.
Methodology


Structure of the Fort
Granite foundation
Scarp wall (brick with shell concrete fill) forms the perimeter of the fort, embrasure openings allowed cannons to fire through
Brick arcade along the interior face of the scarp wall
Vaulted casemate
Inner arcade forms parade ground perimeter
5
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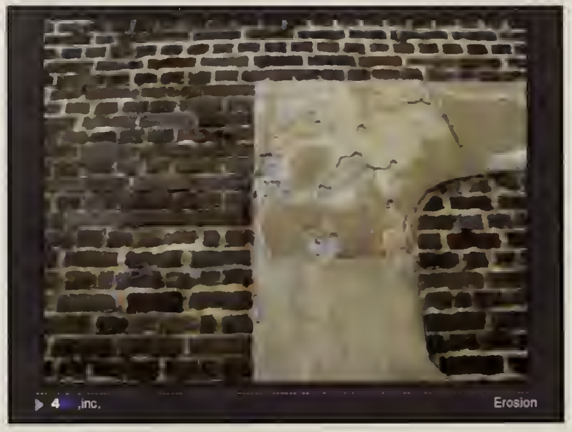
Structure


Findings
Exterior: Surface damage, erosion
4 ,inc.
Findings


4 ,inc.
Erosion


Erosion


Erosion


Erosion


Erosion


Erosion


Erosion


Findings
Exterior: Walls bowing as they approach corners
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Findings


4 ,inc.
Bowing Walls


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Bowing Walls


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Bowing Walls


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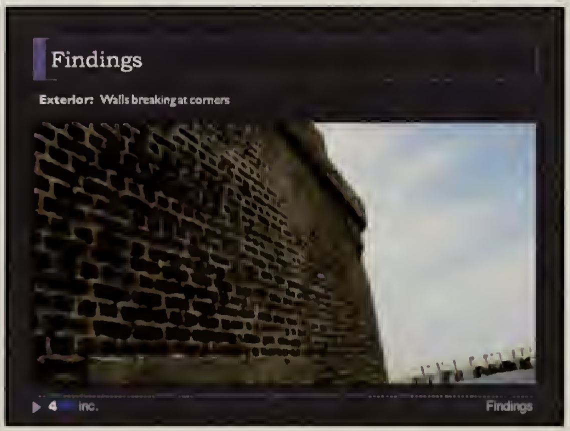
Bowing Walls


Findings
Exterior: Walls breaking at corners
4 inc.
Findings


4 ,inc.
Walls Breaking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Walls Breaking


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Walls Breaking


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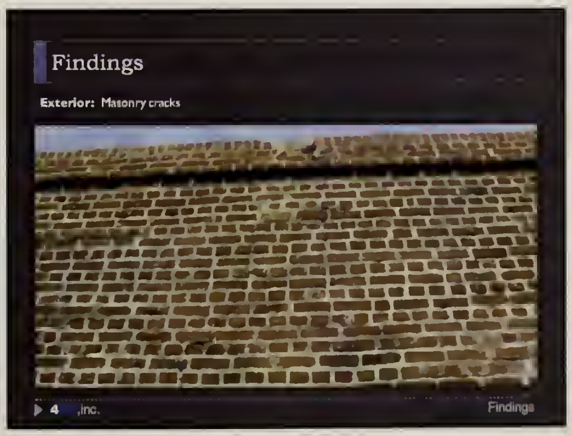
Walls Breaking


Findings
Exterior: Masonry cracks
4 ,inc.
Findings


4 ,inc.
Cracks


4 ,inc.
Cracks


4 ,inc.
Cracks


Findings
Interior: Cracks through arches
4 ,inc.
Findings


4 ,inc.
Arches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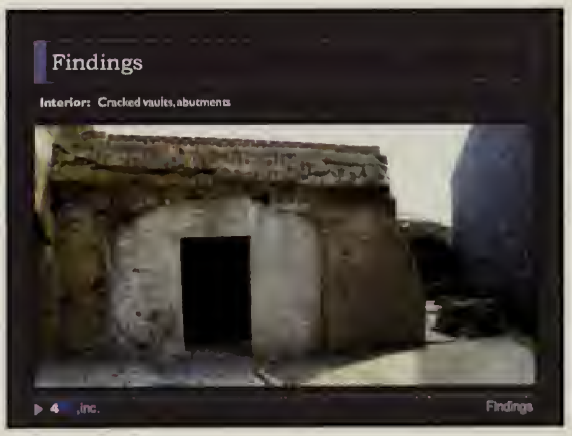
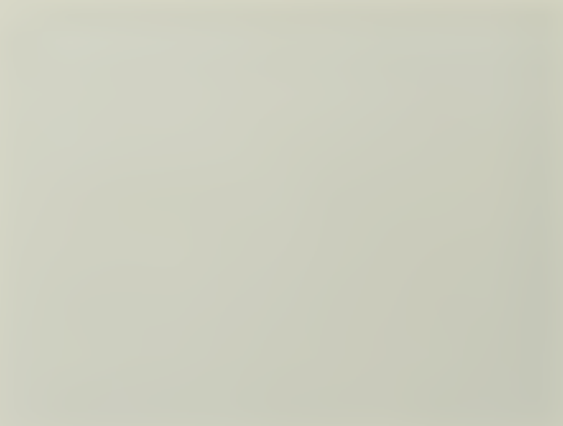
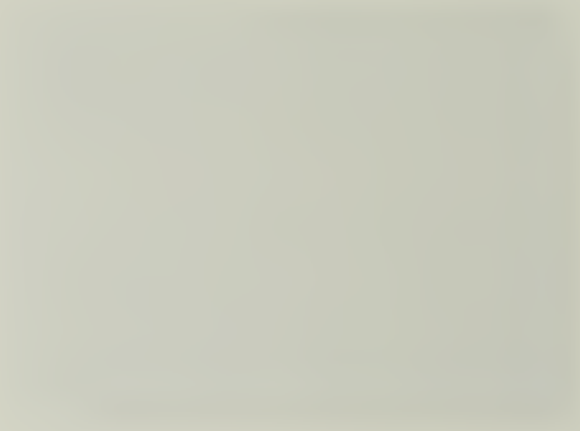
Arches


Findings
Interior: Cracked vaults, abutments
4 ,inc.
Findings



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Vaults


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Vaults


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Vaults


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Vaults


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Vaults


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Vaults

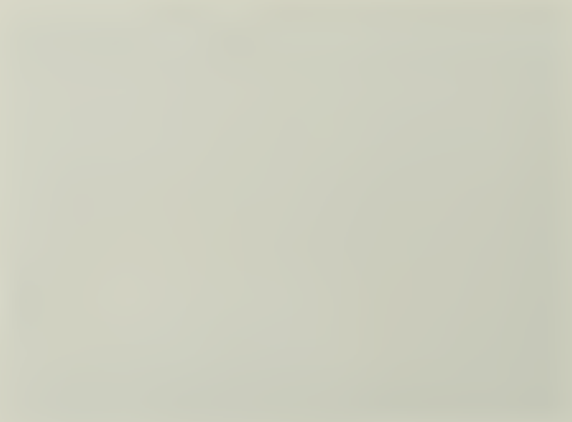

Findings
Interior: Cistern cover damaged
Findings

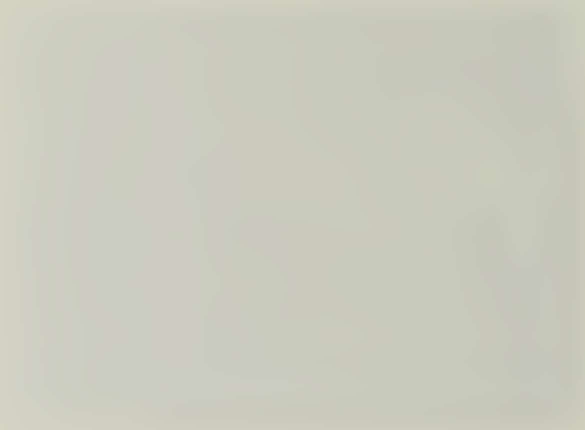

Findings
Interior: Masonry cracks
Findings


Cracks


Cracks


Cracks



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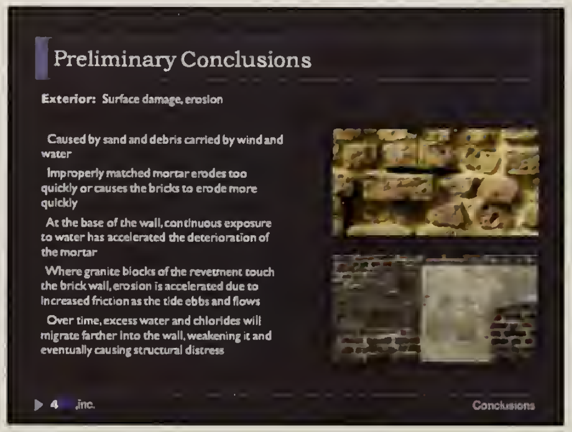
Cracks


Preliminary Conclusions
Exterior: Surface damage, erosion
Caused by sand and debris carried by wind and water
Improperly matched mortar erodes too quickly or causes the bricks to erode more quickly
At the base of the wall, continuous exposure to water has accelerated the deterioration of the mortar
Where granite blocks of the revetment touch the brick wall, erosion is accelerated due to increased friction as the tide ebbs and flows
Over time, excess water and chlorides will migrate farther into the wall, weakening it and eventually causing structural distress
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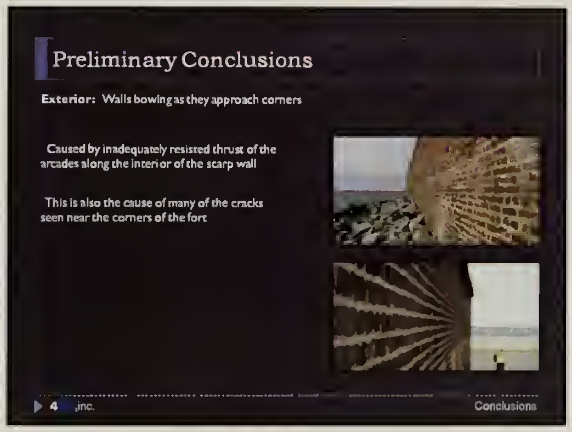
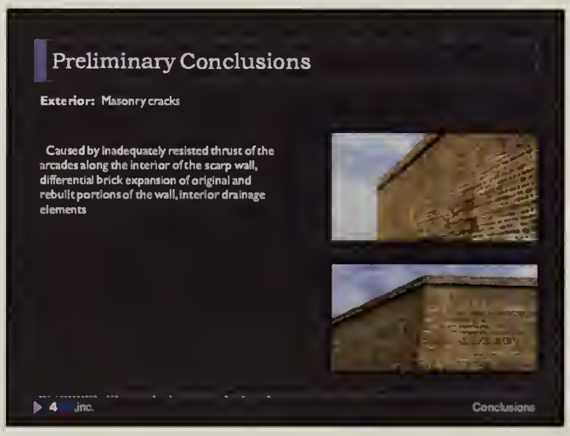
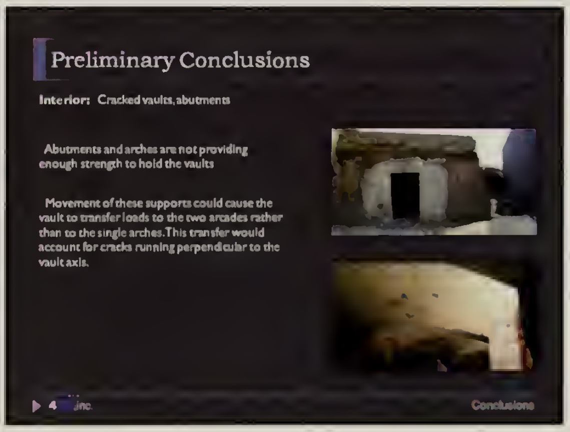
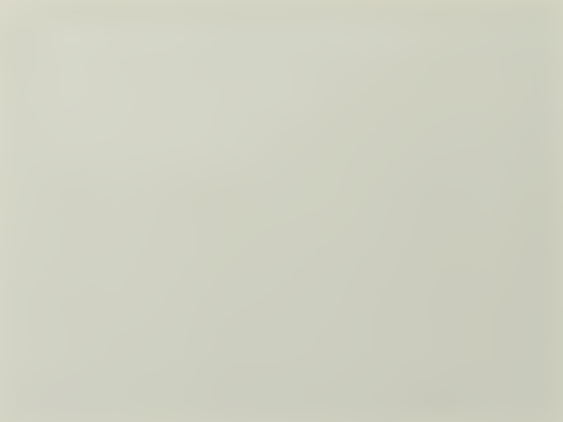
Conclusions

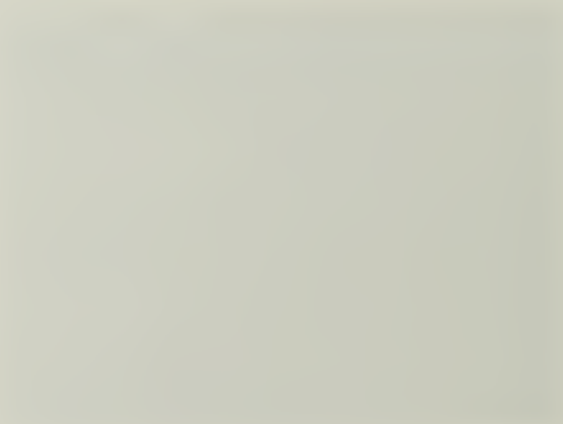

Preliminary Conclusions
Exterior: Walls bowing as they approach corners
Caused by inadequately resisted thrust of the arcades along the interior of the scarp wall
This is also the cause of many of the cracks seen near the corners of the fort
4 ,inc.
Conclusions

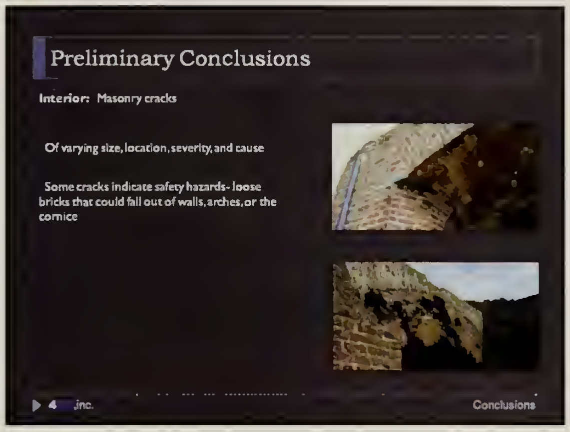

Preliminary Conclusions
Exterior: Masonry cracks
Caused by inadequately resisted thrust of the arcades along the interior of the scarp wall, differential brick expansion of original and rebuilt portions of the wall, interior drainage elements
4 ,inc.
Conclusions


Preliminary Conclusions
Interior: Cracks through arches
Piers, abutments, and scarp wall do not adequately support the arcades
Most cracks found near the ends of arcades, where thrust is least resisted
4 ,inc.
Conclusions

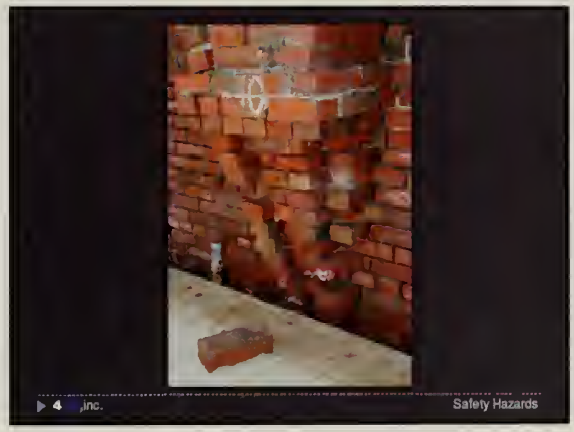

Preliminary Conclusions
Interior: Cracked vaults, abutments
Abutments and arches are not providing enough strength to hold the vaults
Movement of these supports could cause the vault to transfer loads to the two arcades rather than to the single arches. This transfer would account for cracks running perpendicular to the vault axis.
4 ,inc.
Conclusions






Preliminary Conclusions
Interior: Masonry cracks
Of varying size, location, severity, and cause
Some cracks indicate safety hazards- loose bricks that could fall out of walls, arches, or the cornice
4 ,inc.
Conclusions


Initial Recommendations
Immediate Repair of Safety Hazards
Remove loose bricks along arches, cornice (along interior and exterior walls)
Store removed bricks for use in future repairs
Monitor areas around loose bricks, cracks, and damaged arches to watch for further loosening of material
Block off area above cistern until it has been repaired or examined and deemed safe
4 ,inc.
Recommendations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Safety Hazards


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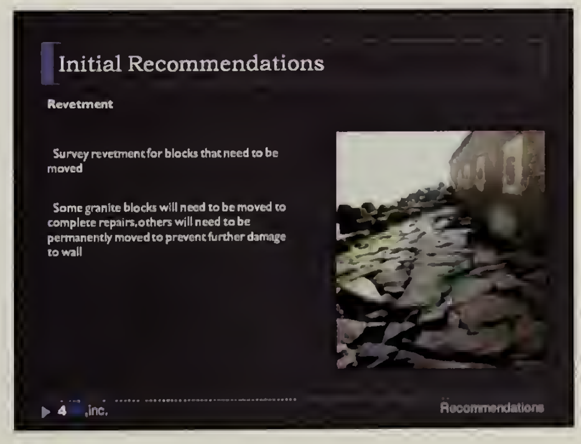
Safety Hazards


Initial Recommendations
Revetment
Survey revetment for blocks that need to be moved
Some granite blocks will need to be moved to complete repairs, others will need to be permanently moved to prevent further damage to wall
4 ,inc.
Recommendations


4 ,inc.
Revetment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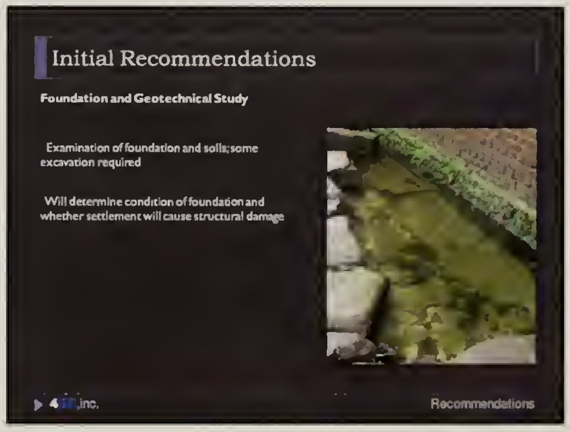
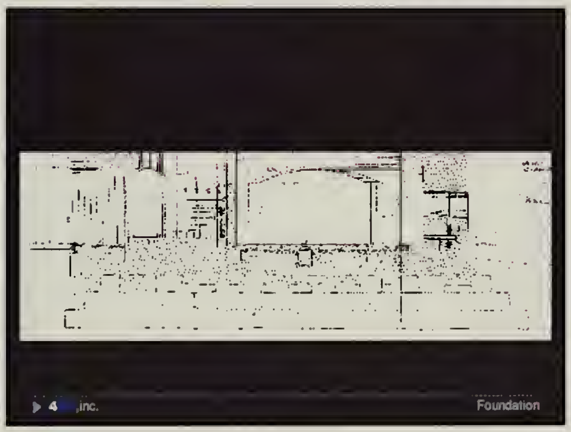
Revetment


Initial Recommendations
Foundation and Geotechnical Study
Examination of foundation and soils; some excavation required
Will determine condition of foundation and whether settlement will cause structural damage
4 ,inc.
Recommendations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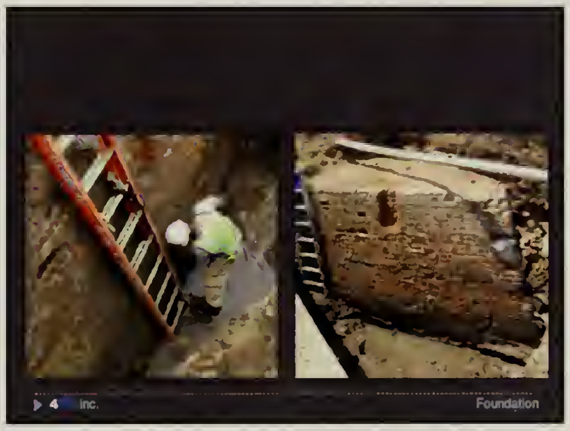
Foundation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Foundation


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Foundation


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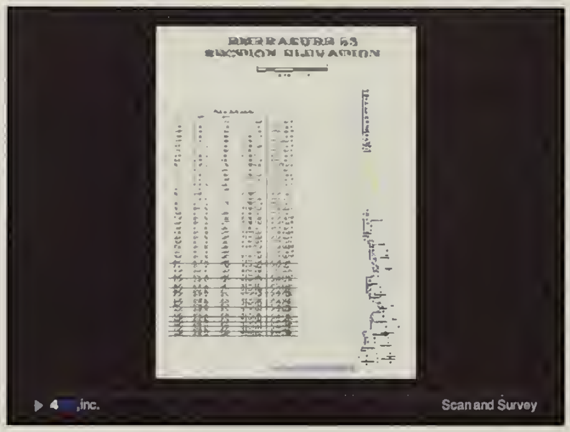
Foundation


Initial Recommendations
Further Studies: Laser Scan and Survey
Laser scans can be used to produce relatively exact pictures of building contours. A survey will help evaluate differential settlement and can be repeated to monitor movement of the structure.
Will provide the geometry of the structure, which will in simplify structural analysis
Installation and survey of settlement bolts will allow a check a the laser scans
4 ,inc.
Recommendations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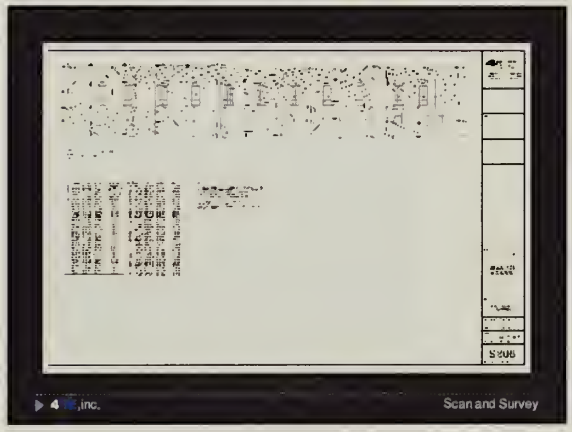
Scan and Survey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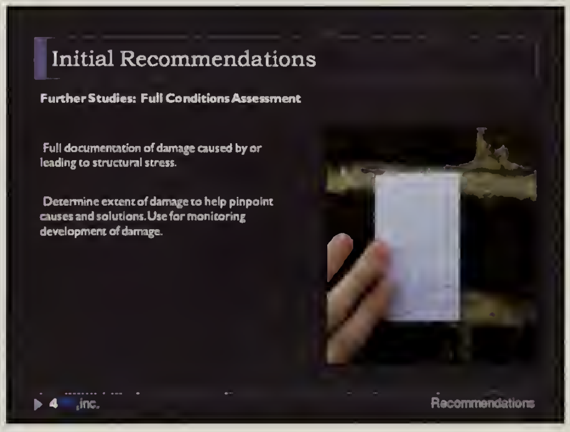
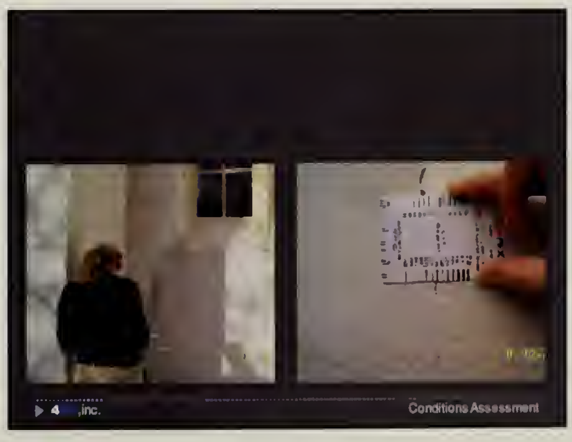
Scan and Survey


Initial Recommendations
Further Studies: Full Conditions Assessment
Full documentation of damage caused by or leading to structural stress.
Determine extent of damage to help pinpoint causes and solutions. Use for monitoring development of damage.
4 ,inc.
Recommendations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Conditions Assessment


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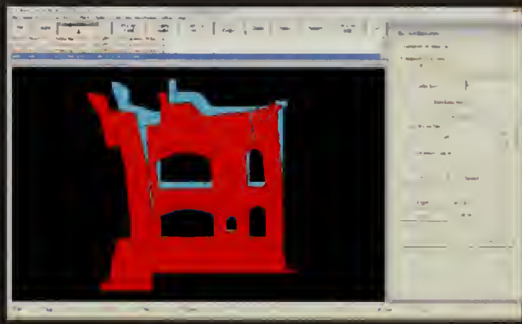
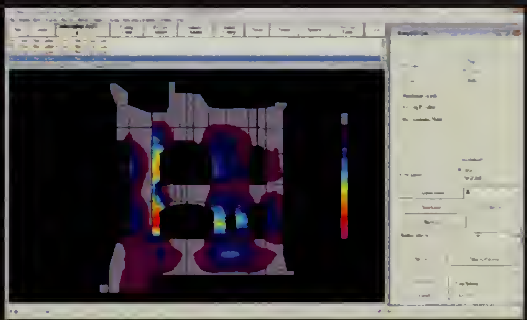
Conditions Assessment

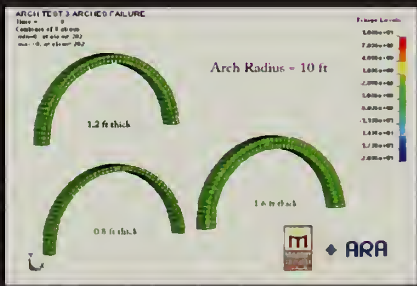
Initial Recommendations

Further Studies: Structural Modeling

- Linear and material non-linear structural modeling
- Determines and illustrates forces and stresses in the structural elements
- Helps predict future behavior of the structure







Initial Recommendations

Summary:

- Repair threats to life safety immediately: Loose bricks and cistern covers
- Move damaging ermoring stones
- Examine the foundation with test pits and do soil borings at several locations around the fort
- Install and survey settlement bolts, perform laser scan and cut sections through the scarp walls
- Perform a thorough structural conditions assessment
- Model elements of the fort to determine future expected behavior and to examine the importance of taking remedial action


Questions?
4 ,inc.
July 2009