Bennett PRESERVATION ENGINEERING PC

STRUCTURAL ENGINEERING FOR EXISTING STRUCTURES
Seismic Retrofit • Historic Preservation • National Historic Landmarks

A Report on Structural Issues in the Demilune at Fort Pulaski National Monument

Cockspur Island near Savannah, Georgia

PMIS 218936



Submitted to:

Lord Aeck Sargent and the National Park Service
Thursday, April 30, 2020

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In September of 2019, the National Park Service contracted with Lord Aeck Sargent and Bennett Preservation Engineering PC, as a subcontractor, for site visits, a structural investigation, detailed recommendations for treatment, and a Class "C" Cost Estimate for structural issues at the demilune at Fort Pulaski National Monument.

The primary concerns noted by the National Park Service focused on cracking, shifting, and deterioration of the east retaining wall along the main north-south pathway through the demilune and on similar problems within the magazines. Secondary issues concerned settlement, erosion, and drainage, minor cracking and delamination of stone, deterioration of finishes, and deterioration of metal elements, particularly ferrous metal.

In order to help with the effort, the National Park Service provided Bennett Preservation Engineering with copies of several historic construction drawings, a 2014 Historic Structure Report (HSR), and a number of historic photographs.

Staff members of Bennett Preservation Engineering have visited Fort Pulaski numerous times, with the most recent visits focused exclusively on evaluation of the bridges and demilune.

This report contains Bennett Preservation Engineering's findings, conclusions, and recommendations, as well as a cost estimate for the recommended work.

General

The demilune at Fort Pulaski National Monument is surrounded on all sides by a moat and is triangular in shape. Located at the rear of the Fort, it was originally constructed to protect the Fort's entrance, but was modified in the 1870s by the addition of earthen mounds to house powder magazines. It was further modified in the 1890s with the addition of the mining casemate at the southeast corner of the demilune.

Retaining Walls within the Demilune

Findings

It is Bennett Preservation Engineering's understanding that much of the concern that prompted the study of the demilune arose out of damage caused by movement of the east retaining wall, the wall running along the main north-south pathway through the demilune. This damage manifested itself as the opening of horizontal cracks between tabby lifts, vertical cracks between pours of the retaining wall, settlement at the south end of the wall and shifting of the top lift of the wall outward toward the walkway.

The east retaining wall, along the right side of the entry walkway through the demilune, retains earth protecting the mining casemate (southeast magazine). This wall, believed to have been built with the 1893 mining casemate, is much later than the 1869-1872 west retaining wall protecting the magazines. It is noticeably deformed, particularly when compared with the west wall. In addition, this east wall shows significant delamination at the lifts and vertical separation at the jointing. In spite of study of the historical material available to us we have not been able to determine with certainty that the wall is or is not supported on pile foundations. If it is fully supported on piles and a platform, then one or the other of these elements is deteriorating. If it is partially supported on fill, it is clear that the lift separation is most severe where the lifts transition from fill support to support on a piled platform below grade.

While Bennett Preservation Engineering has not been able to determine exactly how much the joints between the lifts have opened, nor were we able to determine when the openings became most obvious, we have determined that the damage has been ongoing. Study of photographs taken in the 1930s indicate that, while there was some separation of the lifts at that time and while there was additionally some deterioration of the surface of the tabby, the separation of the lifts and the deterioration of the surface seen now is significantly greater than that in the historic photographs. In addition, the fact that the joints between lifts have been previously filled with mortar, and yet have reopened, indicates ongoing movement.

Study of the 1893 drawings of the mining casemate, located behind this east retaining wall, indicates that the north end of the south segment of the east retaining wall is certainly carried on a pile-supported platform. The entry walls into the mining casemate are also shown as supported on

this piled platform. Additional study of the 1872 drawings of the retaining wall at the south end of the main pathway through the demilune shows that it, too, is supported on a piled platform. However, there is some indication that, even though the two ends of the south segment of the wall are supported on piles, portions of wall itself might not be supported on piles. The wall could be supported only on earth fill, although it not clear whether the mud beneath this wall was excavated and backfilled before the wall was built.

The north segment of the same retaining wall, like the south segment, has experienced some structural movement. Vertical undulations of the lines between the lifts and of the top of the wall itself indicate the likelihood that there was settlement during the pouring of the wall. While the historic drawings do not indicate any piles under this portion of the wall, nor do they call for excavation and backfilling before the pouring of the tabby, we are suspicious that the tabby could have been poured either in a shallow excavation or on top of filled material. It is known that there is a pile-supported platform under the south end of this north segment of the east retaining wall, at the entrance to the mining casemate.

See Appendix A, Figures 1 through 24 for images of damage to the east and west tabby retaining walls within the demilune. See Appendix A, Figure 36 for damage at the mining casement entrance.

Study of the geotechnical report by Geo-Hydro Engineers, Inc. indicates that the first three hand augers, near the south end of the east retaining wall, all hit refusal at a depth at which we would expect to find the tabby concrete of the retaining wall. Note that we had located these hand augers in hopes of having the best chance of getting the most information possible about the wall in the vicinity of the damage at the south end of the wall. The fourth hand auger, north of the north end of the north segment of this wall, confirms our reading of the 1870s and 1890s drawings that there is no platform beneath the demilune as a whole. **See Appendix F.**

The west retaining wall along the entry walkway is in far better condition than is the east wall. Noted is the fact that there are fine vertical cracks along the wall, approximately every four feet, likely located over top of supporting piles below. We are confident that this west wall is supported on piles, both because of its condition and because of the section on the 1870s drawing, that we believe is cut through it, showing such.

See Appendix G, Figures 11 through 14 for additional images of the west retaining wall added in response questions by the National Park Service.

<u>Conclusions</u>

We conclude that portions of the east retaining wall are moving as a result of either consolidation of the soils beneath the wall or deterioration of the piles and platform supporting it, if that system was used. We further conclude that because the two ends of the south segment of the wall and the south end of the north segment are almost certainly supported on the piled platforms, the movement of the now unsupported segment is causing the observed delamination of the lifts.

<u>Recommendations</u>

Our primary recommendations on movement of this east retaining wall are, first, that the movement of the retaining wall be carefully and accurately measured and monitored over time, so

that the National Park Service will have a clear idea of how much the wall is moving and perhaps be able to tie the movement to possible external causes. These causes could include minor seismic events, flooding, severe rains, wind events, and construction vibration. Monitoring should be both across cracks and, where lateral movement is expected, such as at bulges in the north end of the east wall, from an apparently stationary object, such as bolts embedded in the west wall, to similarly fixed objects or points on the east wall.

Secondly, we recommend that, if the National Park Service is able to tie movement of the wall to any cause over which it has some control, such as the passage of heavy construction equipment and materials along the walkway, the National Park Service take steps to significantly limit the weight of any materials and equipment moved up and down this pathway. **See Appendix D for Notes on Monitoring.**

Finally, we recommend that, when monitoring is undertaken in the future, a number of additional hand augers be taken, in hopes of determining more about the geometry of the east retaining wall and of any possible supporting platform. We further recommend that, when the walkway is taken up and replaced in the future, there be a test pit excavated at the east corner of the south end of the walkway, one excavated deep enough to determine the geometry and condition of the supporting timber.

Internal Walls at the "Tee" of the Center Magazine

Findings

Walking west into the center magazine, where the entry corridor tees to the left and the right, the left wall of the entry corridor has broken the corner transition stones at the left leg of the tee. Careful observation shows that the top two stones and the bottom stone are the most severely damaged, with all three stones showing fractures all the way through. On the opposite wall, the east wall, only the second stone is broken. Study of the 1997 Historic American Buildings Survey (HABS) drawings indicates that, at the time of the drawings, only the uppermost stone was broken on the west wall. Assuming that the drawings were completed accurately, it is reasonable to conclude that the structural movement in this area is ongoing and that the damage is likely to get worse.

See Appendix A, Figures 25 through 29 for images of damage to the entry corridor wall within the center magazine.

Study of the 1872 drawings indicates that the center magazine is carried on a pile-supported platform and that the horizontal earth pressure against the entry corridor wall is resisted by the walls themselves and by their attachment to the perpendicular walls leading to the left and the right. It is clear that it would take very little structural movement of one of the entry corridor walls to break the connection to the walls leading off.

Conclusions

Generally, where there is significant damage to an earth retaining structure, there is water pressure having built up in the soil behind the retaining wall. We believe that this wall is likely to continue to be damaged until the horizontal pressure on the backside of it is relieved, likely by installation of a drainage system. However, we are concerned that, even if the water pressure is relieved on the backside of this wall, the unreinforced tabby wall will not be able to resist the horizontal forces of the soil.

Recommendations

In another unrelated tabby structure where there was a similar retaining wall resisting horizontal pressure, and likewise failing in the effort, it was recommended that the soil behind be excavated and a reinforced concrete retaining wall be placed behind the tabby wall. While Bennett Preservation Engineering is not yet ready to make a recommendation of that magnitude, we do recommend that the National Park Service, "do the easy things first" and that a drainage system allowing relief of the water pressure behind the tabby walls be installed. Until this can be funded, we recommend installing monitoring wells (simple perforated pipes) in the soil over the magazines and recording the depth of the water table, at least once a month throughout the year, and after significant rain events. A water table well above the level of the floor of the magazine indicates water pressure on the walls. It would not be necessary to measure rainfall, as rainfall data (and tide data) is available from NOAA.

Moat Retaining Walls

Findings

The demilune retaining walls facing the moat are all carried on pile-supported platforms. The piles are at varying depths, depending on whether they are driven into sand and oyster shell or into a sand and shell layer overlain by soft silty clay with organics (i.e. mud). At the locations where the platform is supported on sand, the platform is laid directly on the sand and tied, presumably with iron bolts, to the sides of the piles. We have seen very similar timber support systems used as late as 1905 to 1915 for another retaining wall/seawall and have seen acceptable performance into the 21st century. In contrast, where the platform at the Fort Pulaski demilune is supported on mud over sand, the horizontal timbers are supported directly on top of the piles and the platform is placed on top of the horizontal timbers.

See Appendix A, Figures 30 through 35 for images of damage to the retaining walls around the moat. See also Appendix B for details of the timber piles and platforms supporting the moat retaining walls.

Conclusions

The geometry of the retaining wall system, retaining earth on the inside of the triangular demilune, causes horizontal deformations in the retaining walls as a result of outward movement of the system. At the south half of the east retaining wall of the moat, a bulge in the top of the wall shows that the soil on top of the 1893 mining casemate has caused displacement of the retaining wall east

of the casemate. Not surprisingly, the wall has also failed in direct tension south of this bulge, at the southeast apex.

Recommendations

While it would be simple to recommend that any wall be repaired where it has failed in direct tension, this recommendation alone would leave the cause of the problem unresolved. Ultimately, it could be important to either brace the retaining wall or remove soil that is causing horizontal pressure in this area, in order to address the direct tension failure. Some soil removal would be a first choice, from a structural standpoint, but would change the shape of the earth cover over the mining casemate. However, before undertaking any such work, much like at the east retaining wall within the demilune, we recommend careful monitoring of the bulge in this wall before the removal of any soil. This initial monitoring will allow the National Park Service to determine whether the soil removal is necessary, and, if done, is successful.

Other Minor Structural Issues

There are several locations within the demilune with visible evidence of structural movement and/or deterioration of historic fabric.

At the entrance to the center magazine complex, the walkway between the two entry walls has dropped. This is likely the result of the consolidation of fill material above the timber platform under the walkway. If the gap between the bottom of the entry wall and the walkway is of concern, we recommend filling it with a lime-based mortar, roughly matching the tabby above, or monitoring the movement along with other monitoring mentioned in this report.

At the entry doorway to the center magazine the quoins of the left or south door jamb are fractured. This is likely as a result of stress caused by differential movement of the tabby and the granite quoins, as the two respond completely differently to loads, having significantly different moduli of elasticity. We recommend only monitoring of these cracks.

See Appendix G, Figures 8 through 10 for additional images of these cracks.

Within the center magazine, the west magazine and the north magazine, there are areas of deterioration having a gentle downward slope appearing to run from pour line to pour line. After examining several of these closely with National Park Service personnel, we believe that these are most likely not cracks but pour lines themselves, where one pour in the forms was stopped and another started. But on the possibility that these are cracks or lines of slippage, we recommend installing four small bolts in a roughly square pattern, two on each side of the pour line. Measurements taken diagonally across the bolt pattern can determine whether there is any slippage and measurements taken perpendicular to the pour line can determine where there is any separation.

See Appendix G, Figures 1 through 7 for additional images of the west retaining wall.

In numerous locations around both the demilune and the fort, there is exposed ferrous metal that is corroding. While the cause of the corrosion is likely attributed to the embedded chlorides within the iron, removing chlorides and preventing their return in a marine environment is extremely difficult. We recommend that metal elements be removed where possible, that the iron be treated, likely with long-term soda baths, and then be re-coated as a protective measure. However, before such work is undertaken, we recommend that a metals conservator be engaged to evaluate the depth of the deterioration and confirm the recommended treatment.

In several locations around the demilune, the tabby has been parged with a hard gray Portland cement slurry. We suspect that this was done in an effort to slow deterioration of the tabby. While we are aware now that such parging can be particularly damaging in that it forces water to migrate around the parging, accelerating deterioration at the edges of the parge, we cannot recommend removal of the parge, as removal will take significant amounts of the tabby with it. Instead we recommend watching the areas of tabby around the edges of the parge, and if severe deterioration is found, then removing the hard layer of cement.

See Appendix G, Figures 15 and 16 for an image of the parge and of the damage that is done when the parge is removed.

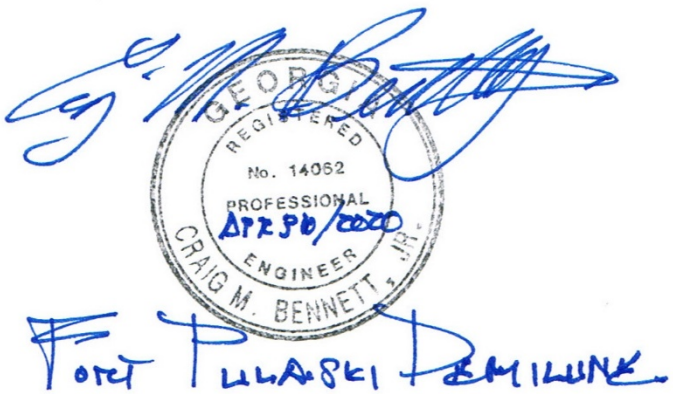
The findings, conclusions, and recommendations in this report have been written and reviewed by Craig M. Bennett, Jr. PE of Bennett Preservation Engineering PC, with additional help from Amanda E. Brown, Andrea J. Cooper, EIT, Taylor C. Frost, and John S. Bennett, SE, PE of this firm. We have based this report on information available to us at this time. If conditions change or more information becomes available, we would like to have the opportunity to reevaluate our conclusions and recommendations.

We understand that the information submitted in this report could require additional explanation. We welcome the opportunity to review this information and to answer any questions. We appreciate the opportunity to present this report and hope that we may be of additional service in the future.

Sincerely,

Amanda Brown

Amanda Brown
Architectural Preservationist
Bennett Preservation Engineering PC



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

The following photographs were taken by Bennett Preservation Engineering staff on August 18, August 21 and November 14, 2019. Staff has taken just over 1100 photos of the demilune and associated bridges. All of these will be available to the National Park Service.



Figure 1: Drawbridge #1 to the demilune. East tabby retaining wall is in the background.



Figure 2: 1934 photograph of the demilune entrance near Drawbridge #1 (provided by the NPS).



Figure 3: 1934 photograph of the demilune entrance near Drawbridge #1 (provided by the NPS).



Figure 4: East tabby retaining wall on the demilune near Drawbridge #1.

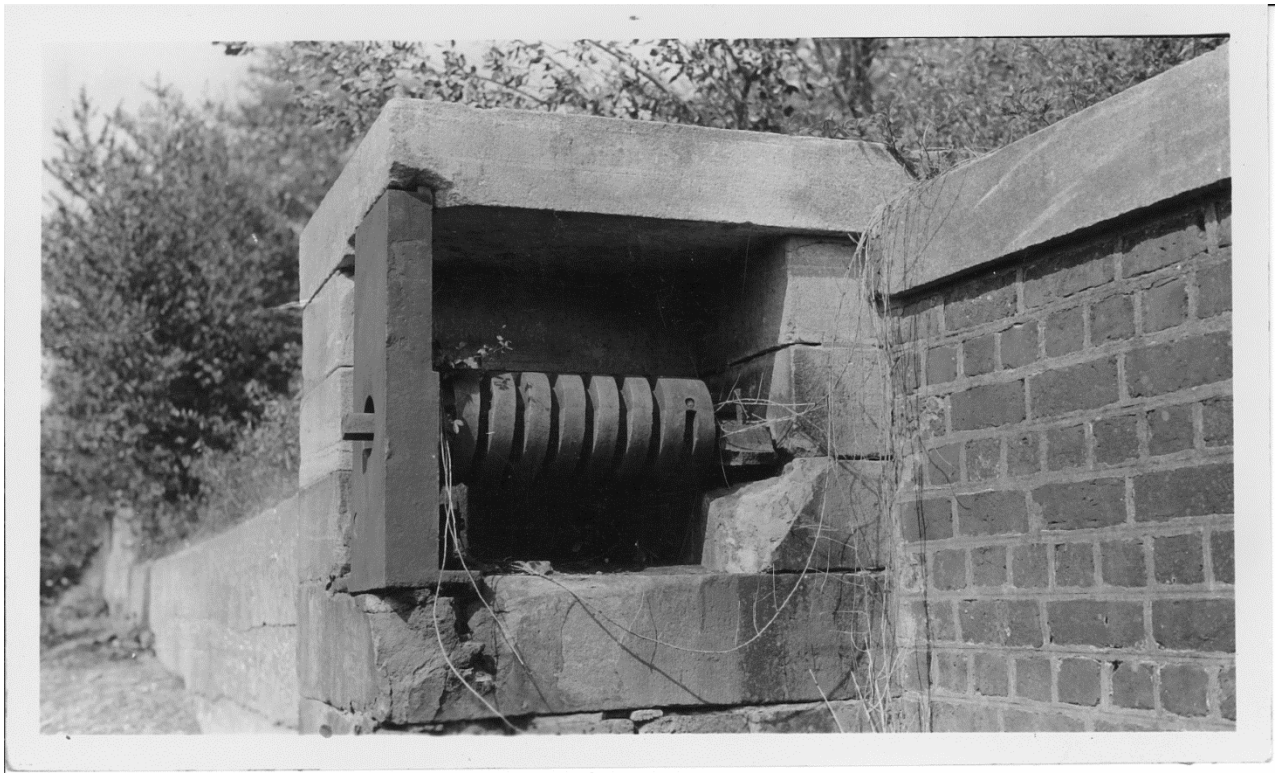


Figure 5: 1934 photograph of the east pier at Drawbridge #1 (provided by the NPS).



Figure 6: Deformation of the north segment of the east tabby wall on the demilune.



Figure 7: Deformation of the east tabby wall on the demilune, looking south.



Figure 8: Lack of significant deformation of the west tabby wall on the demilune.



Figure 9: East tabby wall on the demilune near Drawbridge #1.



Figure 10: East tabby wall on the demilune near Drawbridge #1.



Figure 11: Masonry cracks at the east pier of Drawbridge #1.



Figure 12: Masonry cracks at the east pier of Drawbridge #1.



Figure 13: East tabby wall.



Figure 14: East tabby wall, south end of the south segment.



Figure 15: East tabby wall.



Figure 16: East tabby wall, north end of the south segment.



Figure 17: East tabby wall, south end of the north segment.



Figure 18: East tabby wall, north segment.



Figure 19: East tabby wall.



Figure 20: East tabby wall.



Figure 21: East tabby wall, north end of the north segment.



Figure 22: North end of the east tabby wall, looking south.



Figure 23: West tabby wall on the demilune near Drawbridge #1.



Figure 24: North end of the west tabby wall.



Figure 25: Entrance to the Center Magazine.



Figure 26: Left wall of the entry corridor in the Center Magazine at the tee.



Figure 27: Left wall of the entry corridor in the Center Magazine at the tee.



Figure 28: Settlement at the entrance into the Center Magazine.



Figure 29: South leg of the tee in the Center Magazine.



Figure 30: 1934 photograph of southeast retaining wall of the demilune (provided by the NPS).



Figure 31: Overall deformation: southeast retaining wall of the demilune.

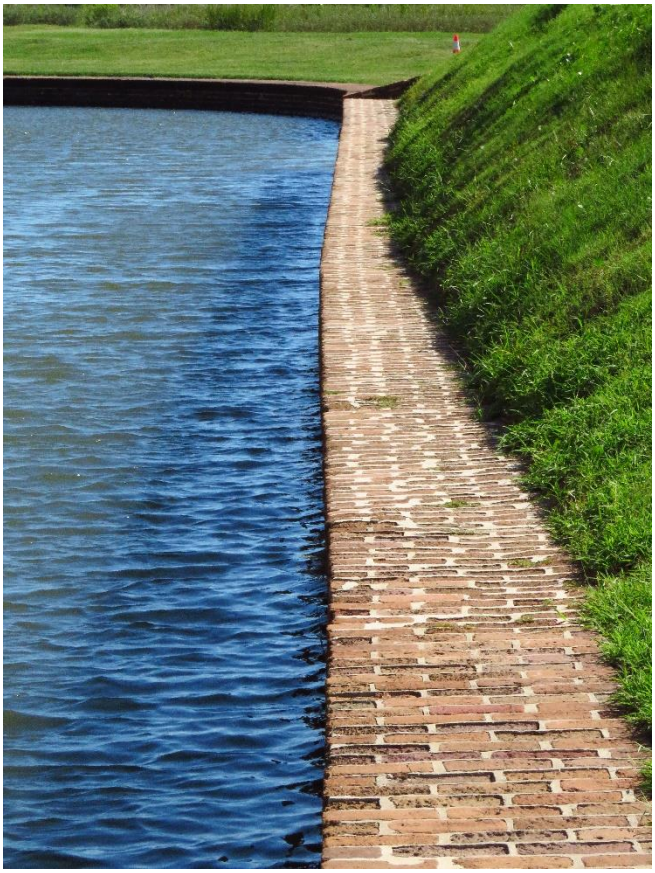


Figure 32: Overall deformation: bulge in the southeast retaining wall of the demilune.



Figure 33: Minimal deformation in the northeast retaining wall of the demilune.



Figure 34: Masonry cracks in the brick retaining wall of the demilune, southeast apex.



Figure 35: Masonry cracks in the brick retaining wall of the demilune, north of the apex.



Figure 36: Surface corrosion of iron at the Southeast Magazine (Mining Casement) entrance.

The following excerpts of the historic drawings provided by the National Park Service are intended to show construction details of the magazines, retaining walls and the pile-supported platforms under those elements.

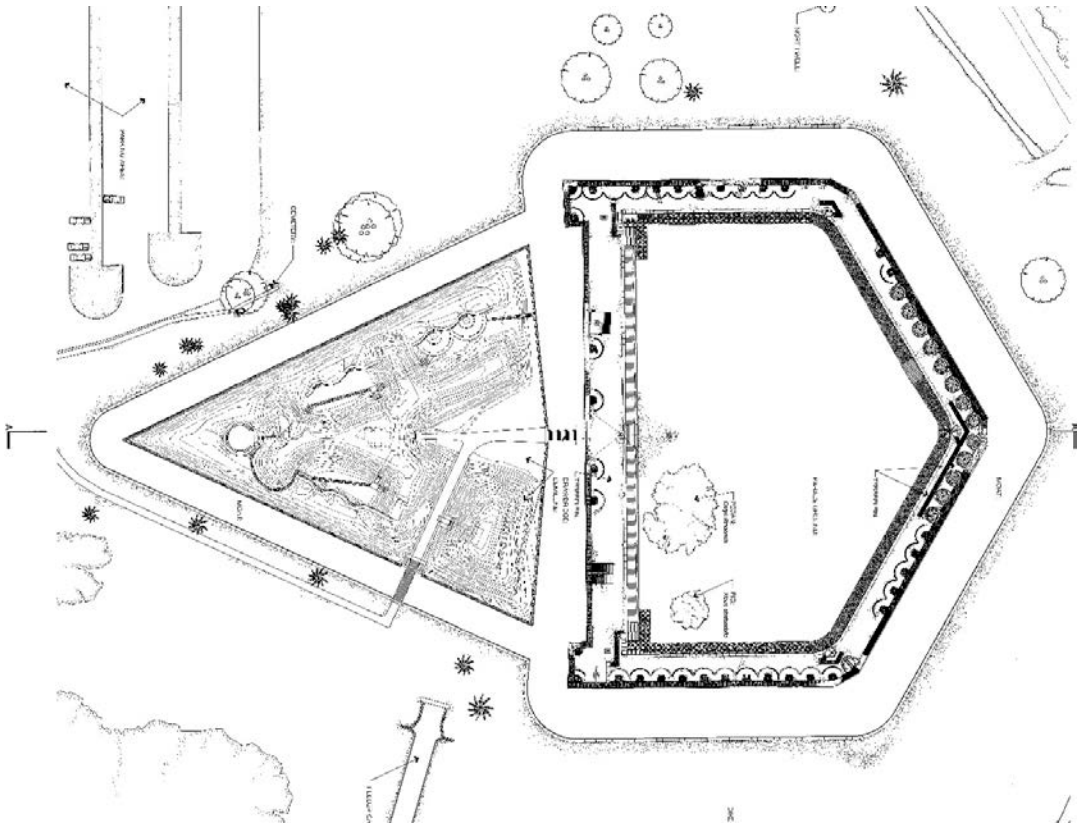


Figure 1: Overview of Fort Pulaski National Monument (HABS drawing provided by the NPS).

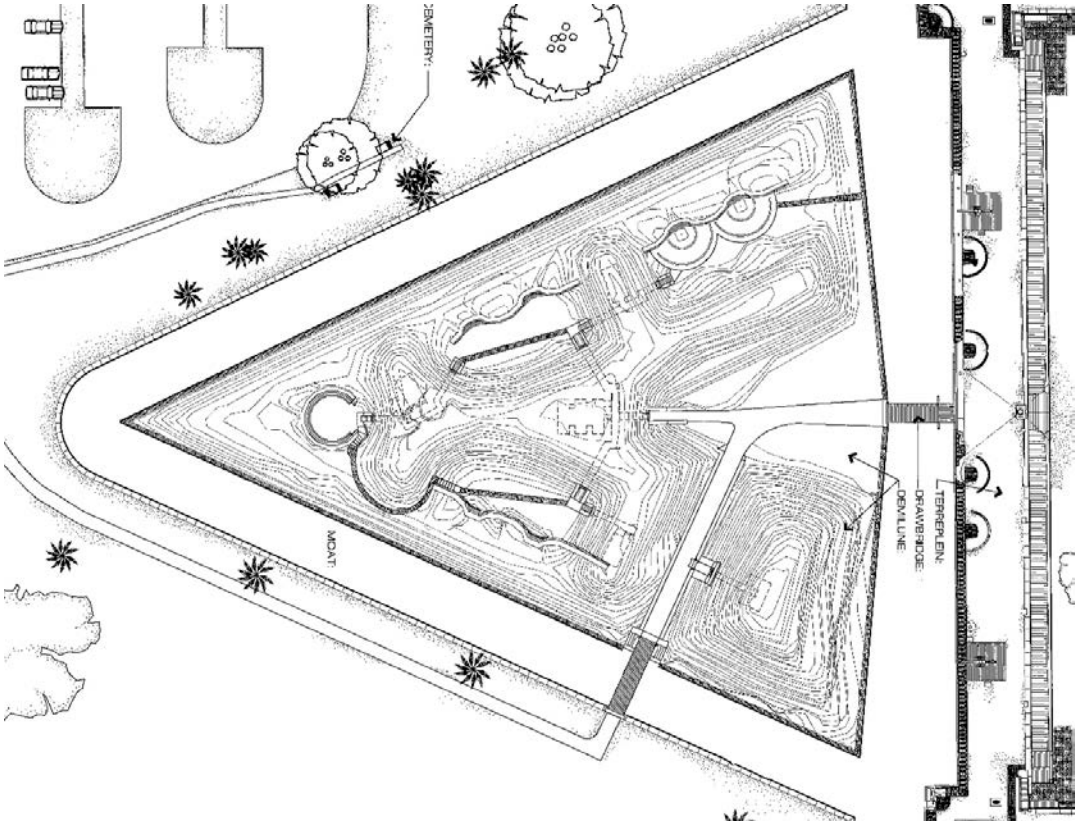


Figure 2: Overview of the demilune at Fort Pulaski (HABS drawing provided by the NPS).

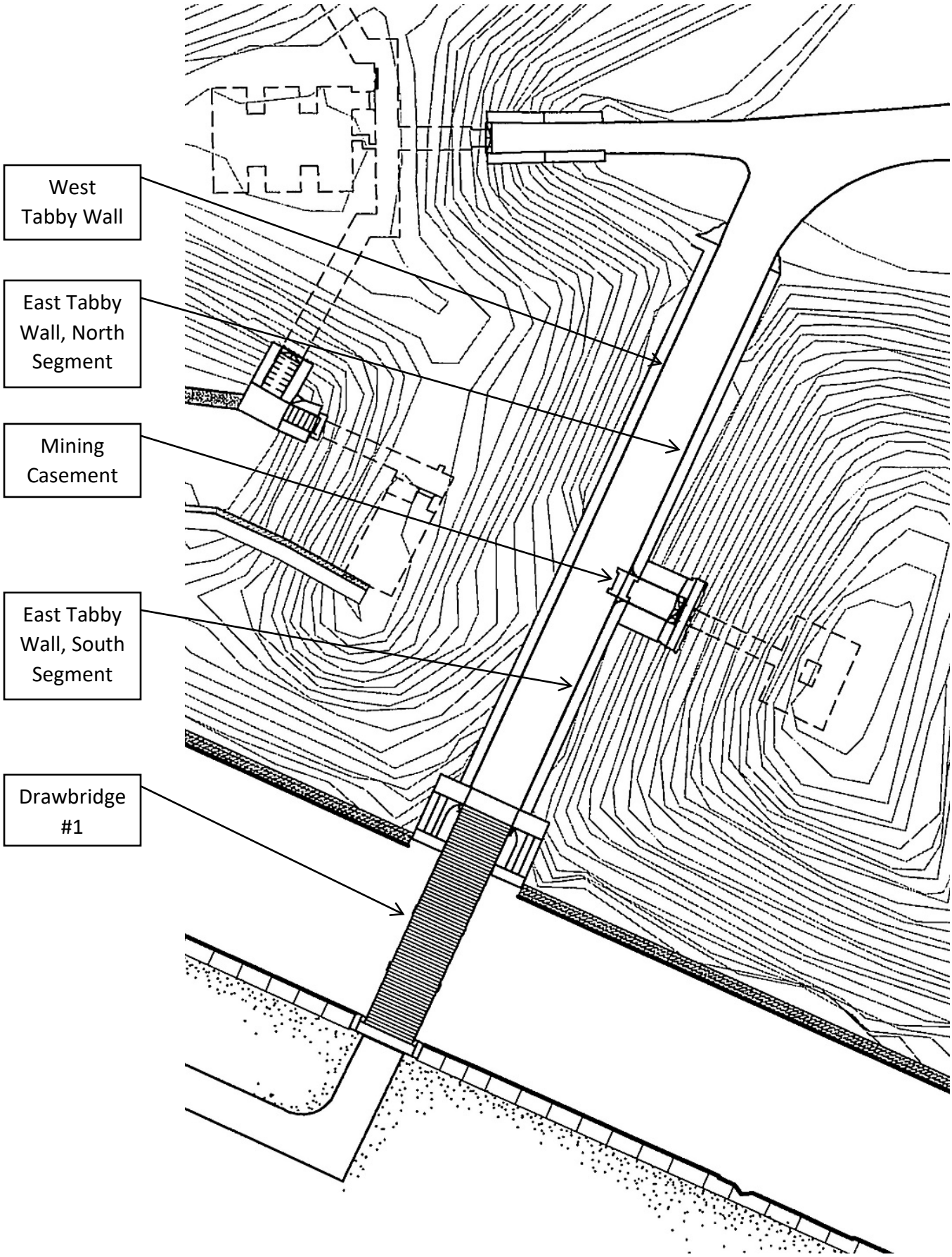


Figure 3: East and west tabby walls in the demilune at Drawbridge #1 (HABS drawing provided by the NPS).

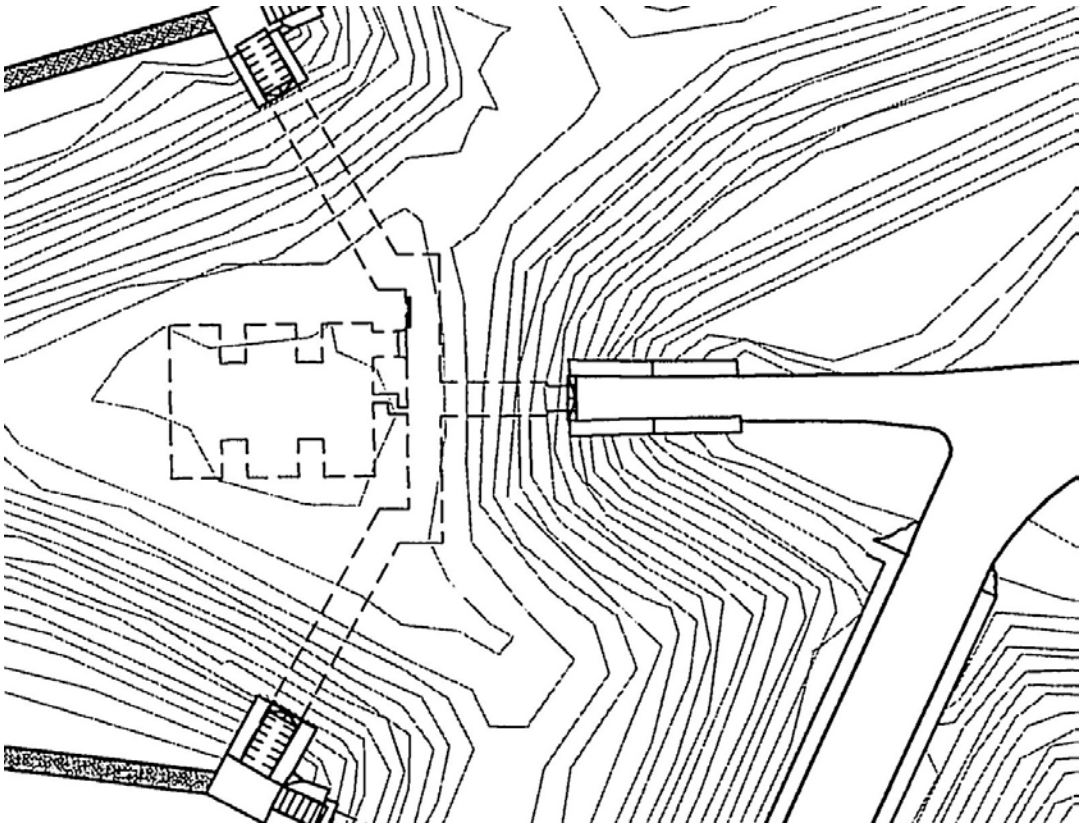


Figure 4: Plan of the central magazine (HABS drawing provided by the NPS).

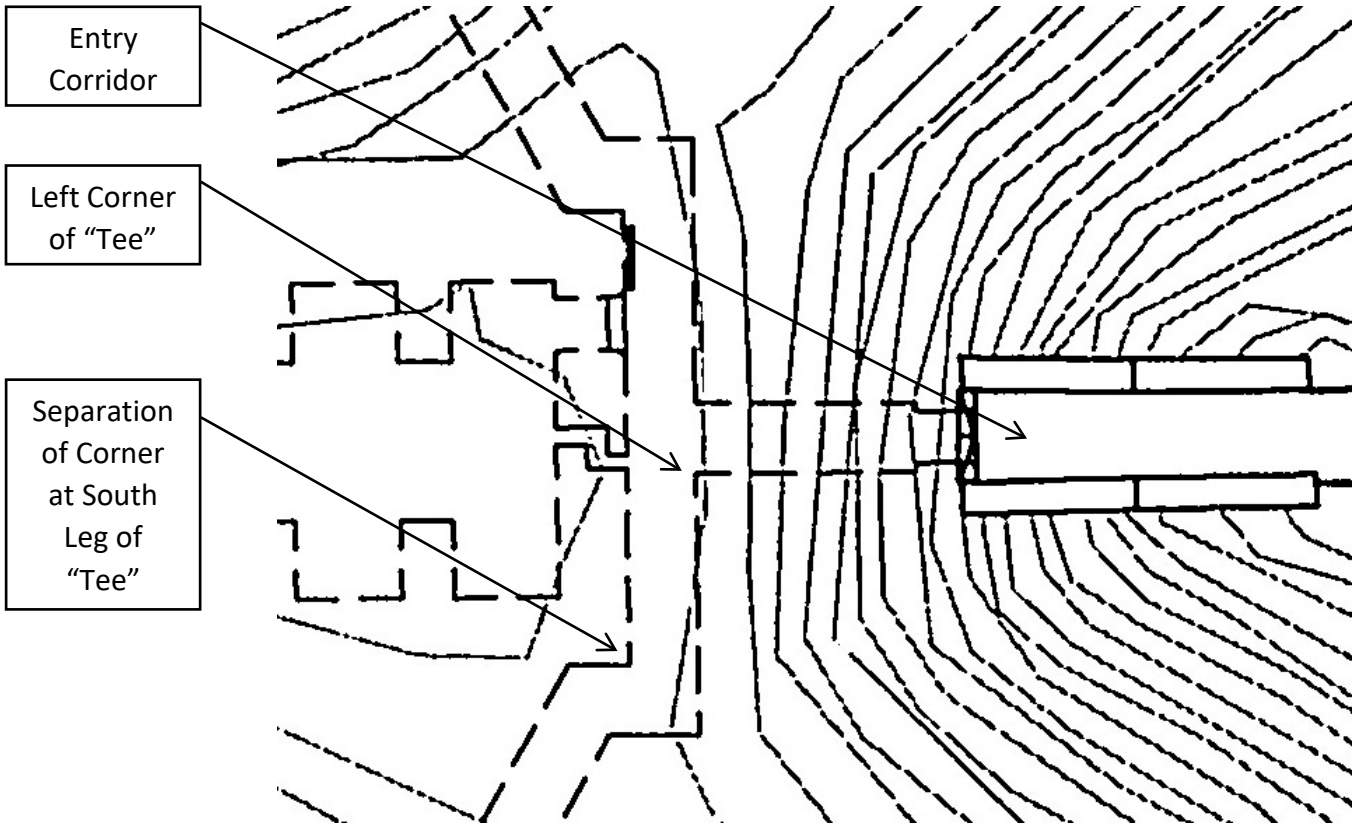


Figure 5: Entry corridor and "tee" in the central magazine (HABS drawing provided by the NPS).

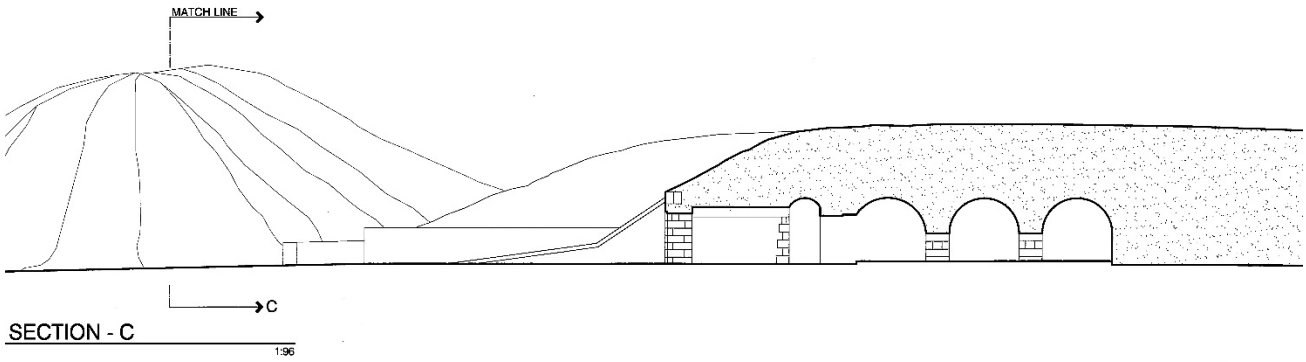


Figure 6: Section through demilune and central magazine (HABS drawing provided by the NPS).

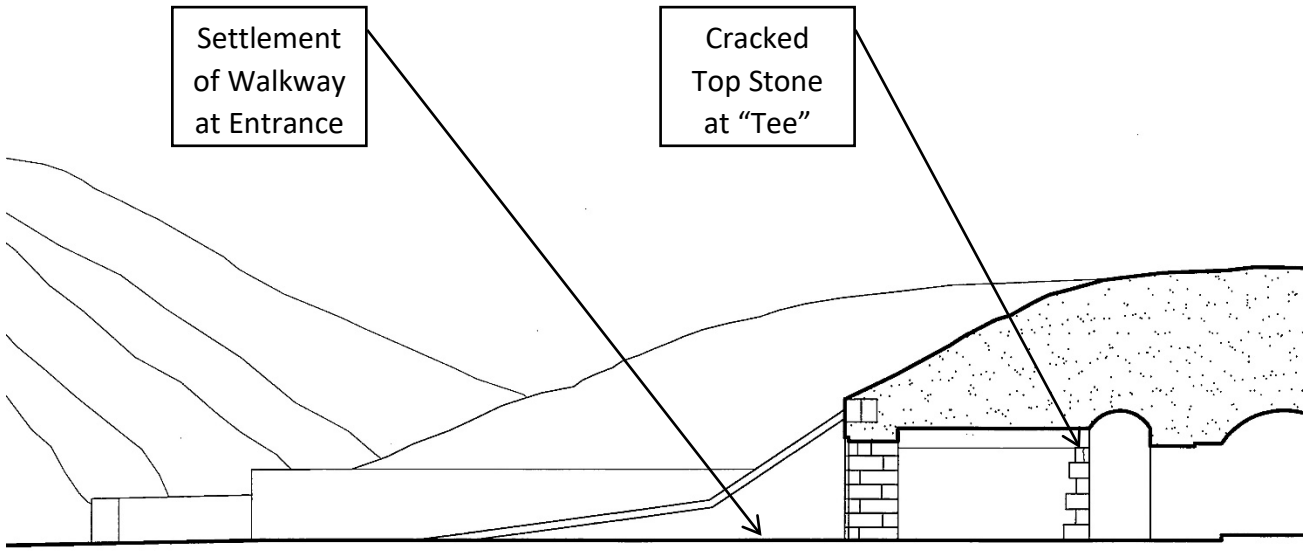


Figure 7: Section through central magazine showing cracked top stone (HABS drawing provided by the NPS).

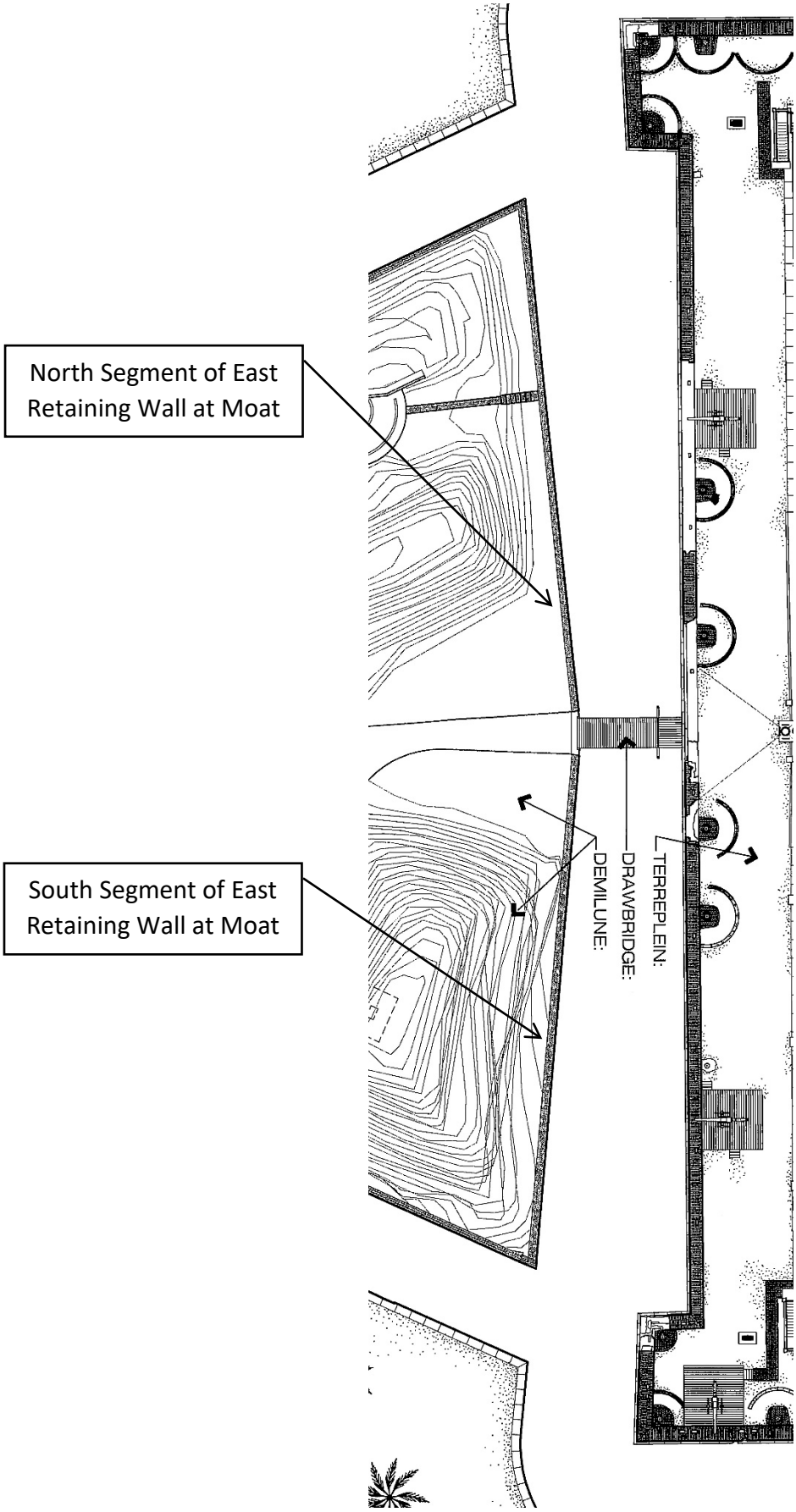


Figure 8: Overview of the east retaining wall of the demilune at the moat (HABS drawing provided by the NPS).

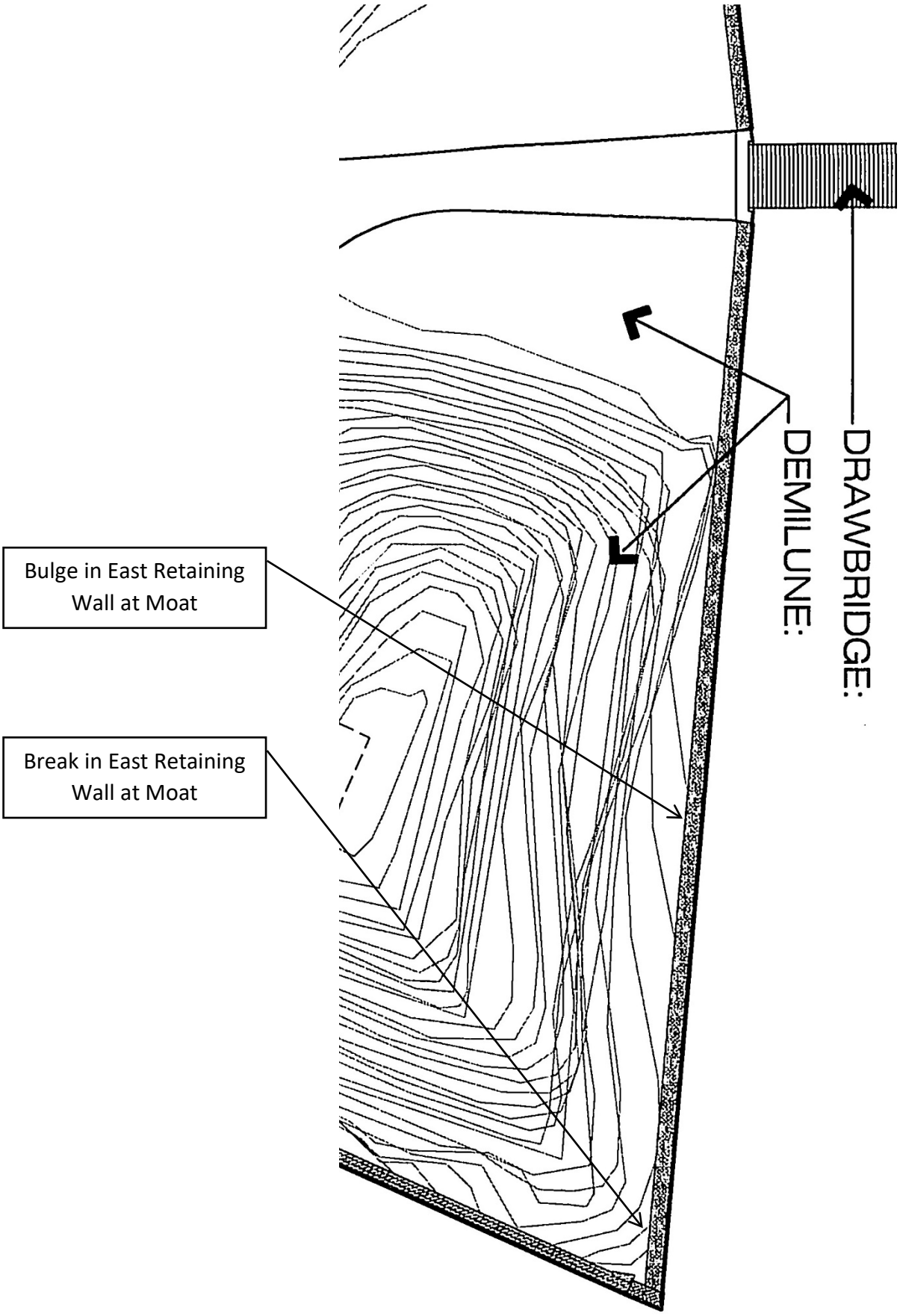


Figure 9: Area of deformation in the south segment of the wall at the moat (HABS drawing provided by the NPS).

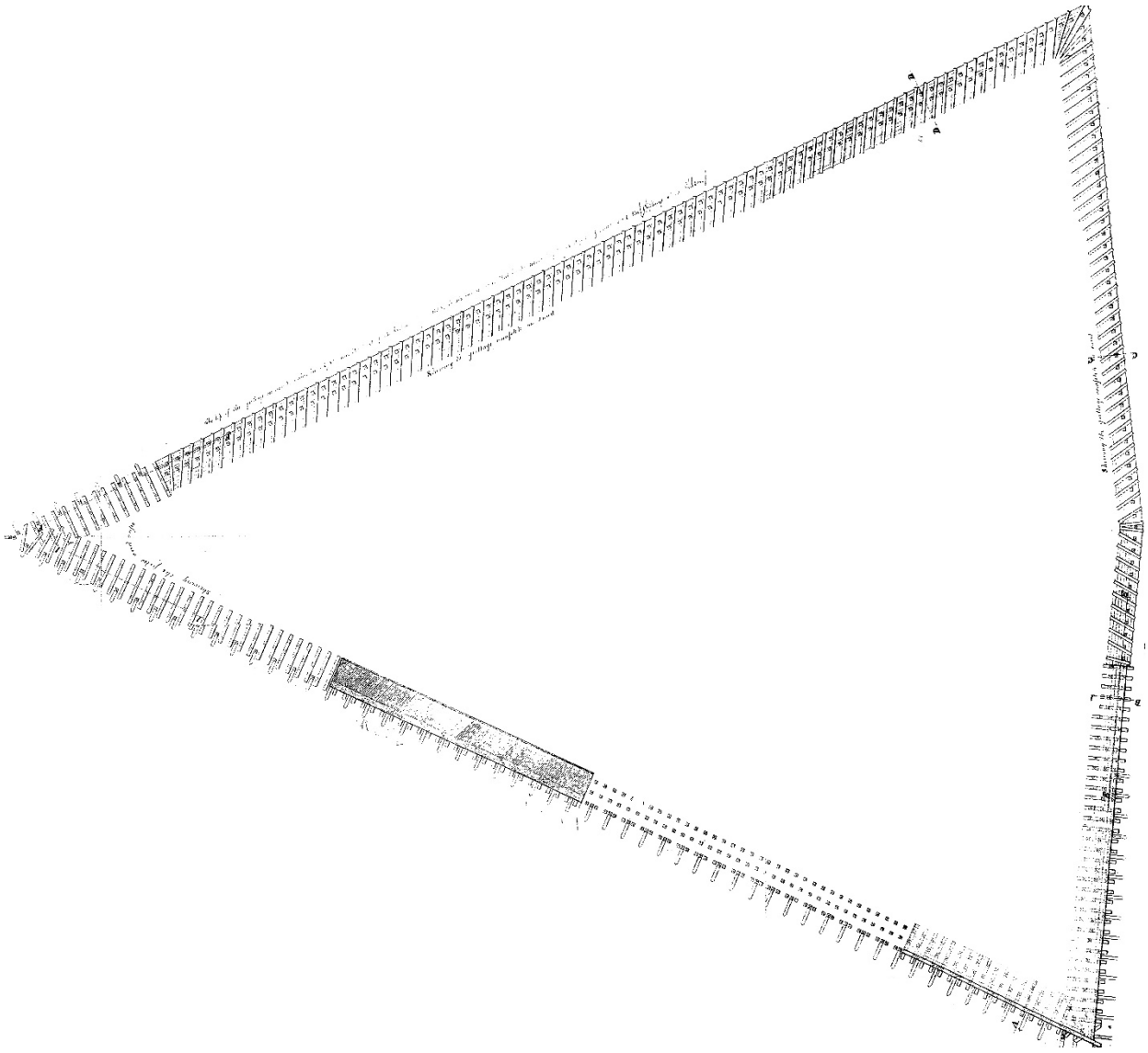


Figure 10: Overview of demilune pile-supported platform (1899 drawing provided by the NPS).

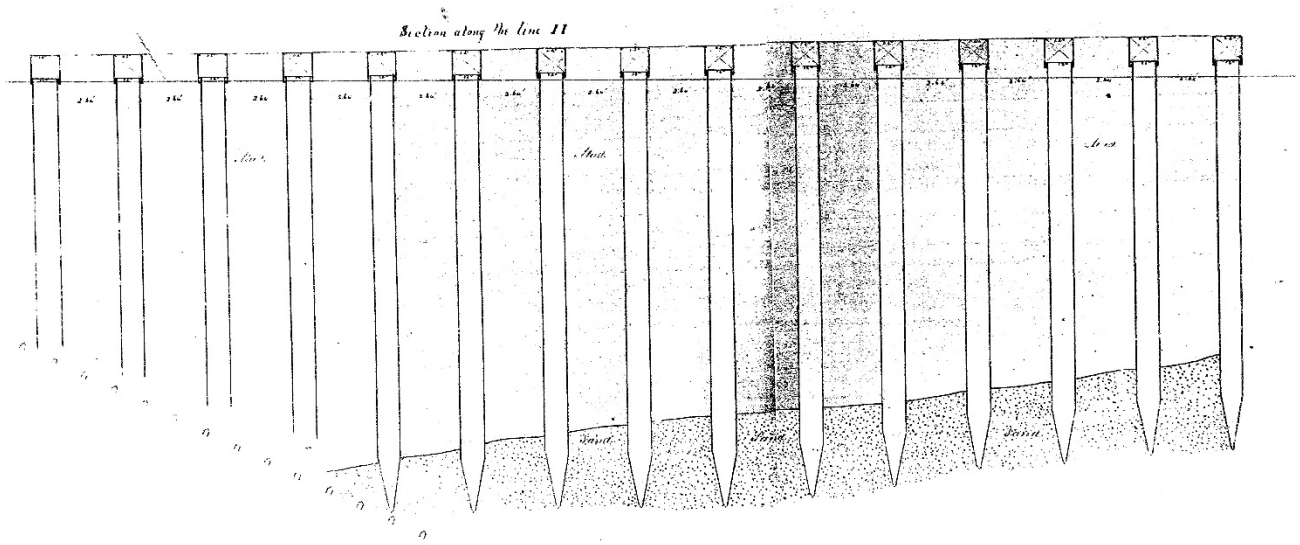


Figure 11: Detail section of piles (1899 drawing provided by the NPS).

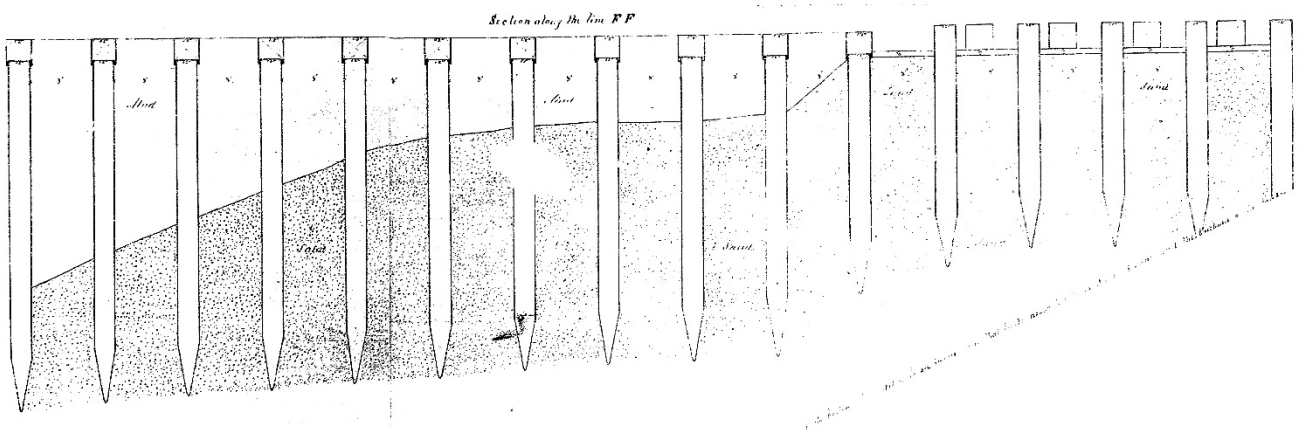


Figure 12: Detail section of piles (1899 drawing provided by the NPS).

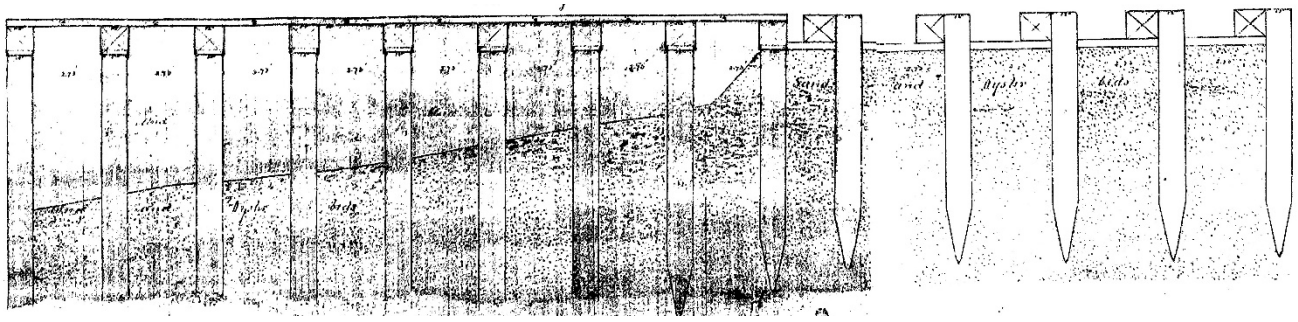


Figure 13: Detail section of piles (1899 drawing provided by the NPS).

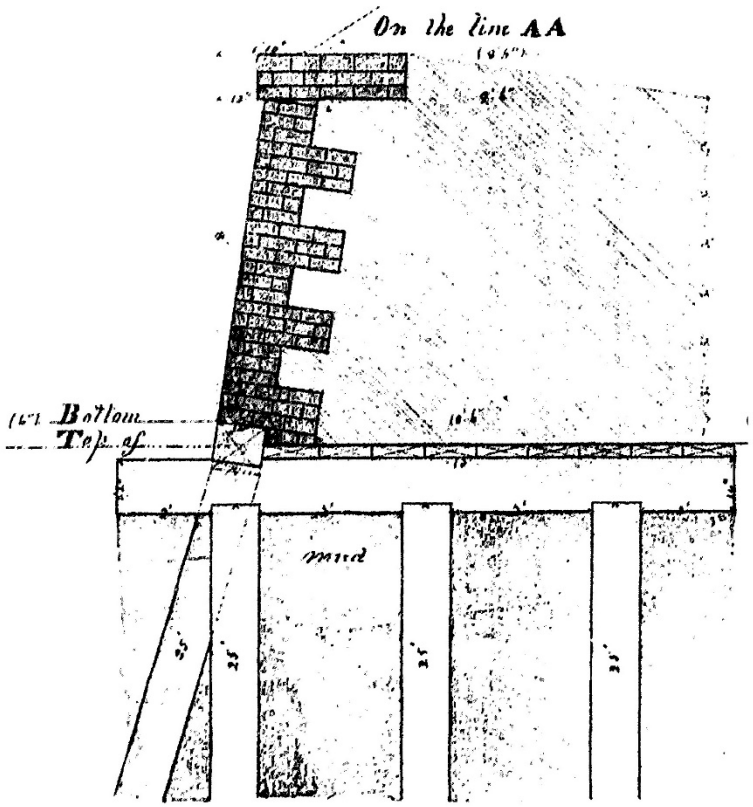


Figure 14: Profile of pile-supported platform and masonry (1899 drawing provided by the NPS).

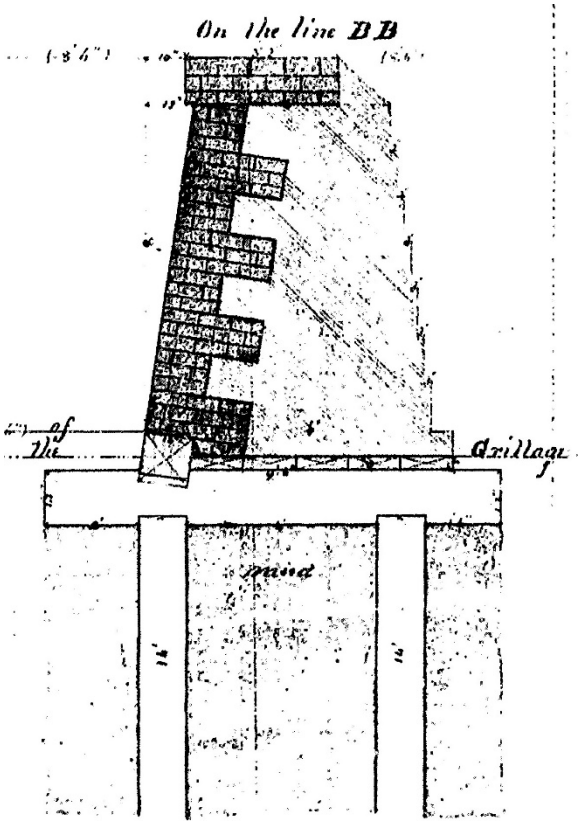


Figure 15: Profile of pile-supported platform and masonry (1899 drawing provided by the NPS).

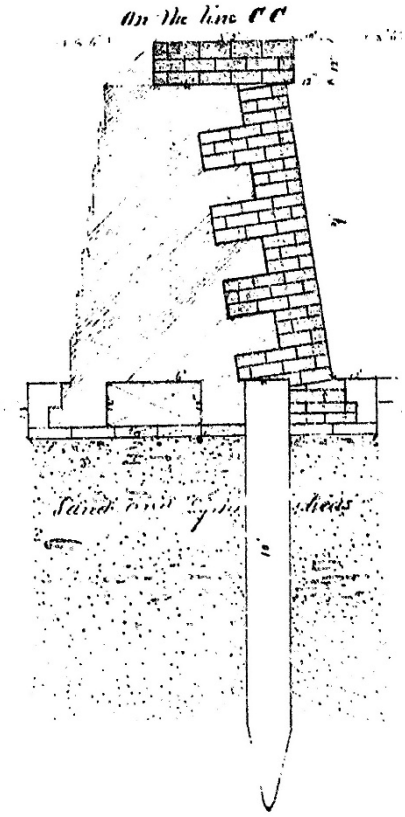


Figure 16: Profile of pile-supported platform and masonry (1899 drawing provided by the NPS).

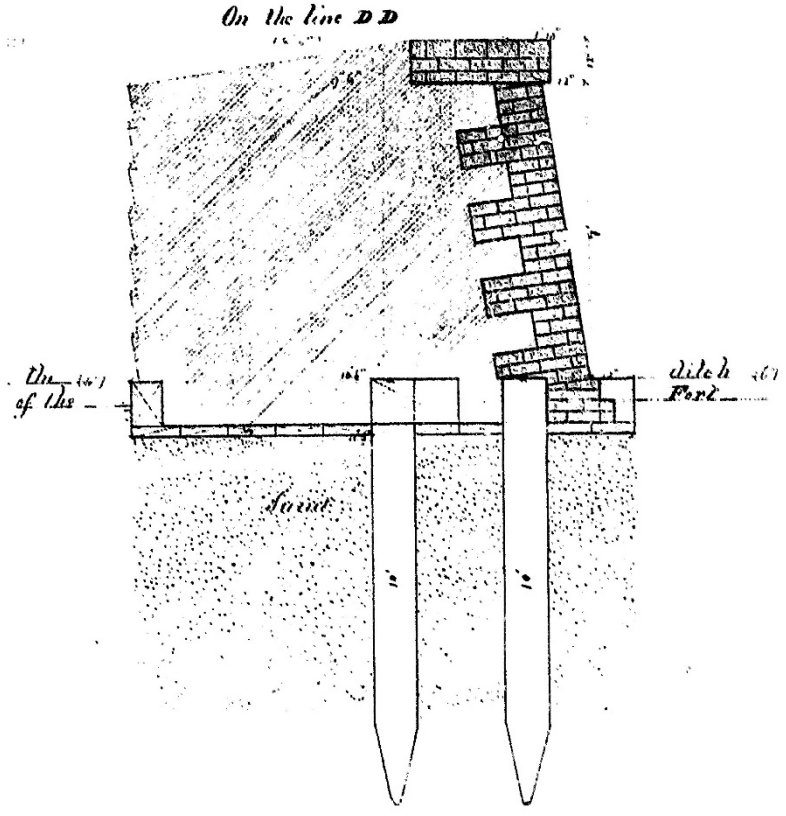


Figure 17: Profile of pile-supported platform and masonry (1899 drawing provided by the NPS).

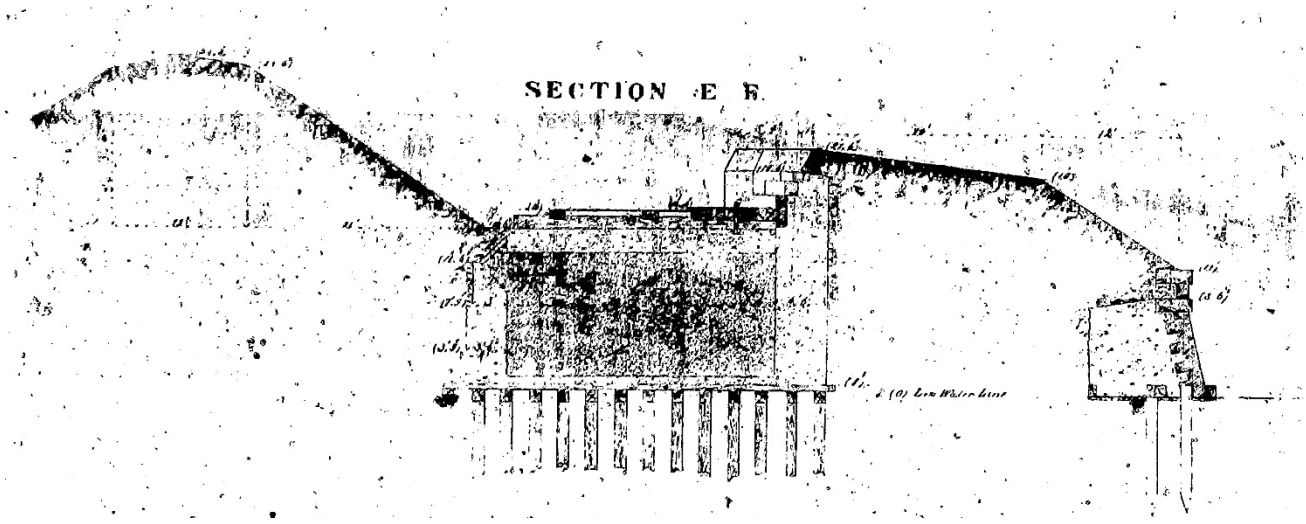


Figure 18: Typical retaining walls supported on piles (1875 drawing provided by the NPS).

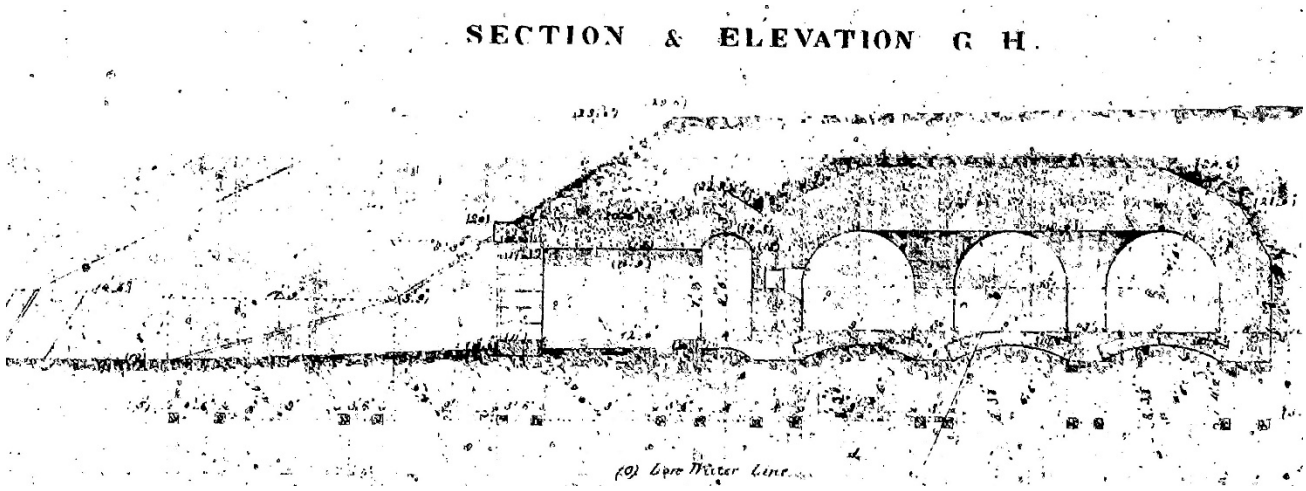


Figure 19: Central magazine and entry wall supported on piles (1875 drawing provided by the NPS).

The following laser scans have been put in registration and scaled to fit onto standard 22x34 inch sheets, reduced at 50% reduction to 11x17. Their value is less in showing the characteristics of the individual walls and more in showing the differences between the east and west tabby walls.



1 S201 NORTH END OF EAST WALL
1/4" = 1'-0"



2 S201 SOUTH END OF EAST WALL
1/4" = 1'-0"

NOT FOR CONSTRUCTION

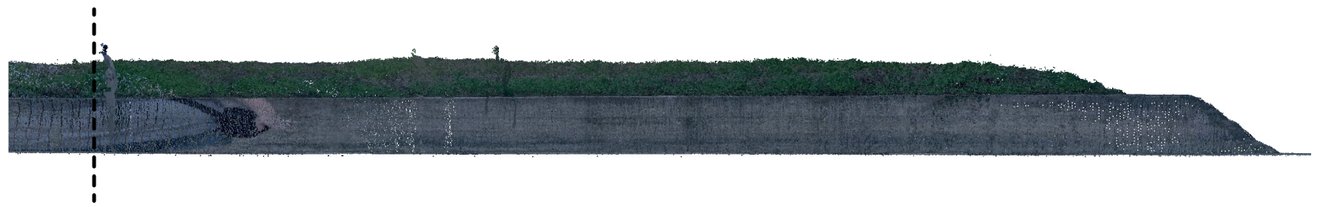
Bennett PRESERVATION ENGINEERING PC

Drawn By: AJC
Checked By: CMB
Phase: AS-BUILTS

Job Name: FORT PULASKI DEMILUNE
Sheet Title: ELEVATIONS

Date of Issue: April 15, 2020
Job Number: 14-037C
Sheet Number: S201

ON A FULL SIZE DRAWING, THIS LINE IS 12 INCHES LONG



1 S202 NORTH END OF WEST WALL
1/4" = 1'-0"



2 S202 SOUTH END OF WEST WALL
1/4" = 1'-0"

NOT FOR CONSTRUCTION

Bennett PRESERVATION ENGINEERING PC

Drawn By: AJC
Checked By: CMB
Phase: AS-BUILTS

Job Name: FORT PULASKI DEMILUNE
Sheet Title: ELEVATIONS

Date of Issue: April 15, 2020
Job Number: 14-037C
Sheet Number: S202
44

ON A FULL SIZE DRAWING, THIS LINE IS 12 INCHES LONG

We have recommended in this report that the National Park Service carefully monitor a number of aspects of the moment of the demilune. Specifically, we recommend monitoring:

- The movement of the moat wall outward at the bulge,
- The settlement and horizontal movement of the east tabby retaining wall, and
- The movement of the tabby and stone elements in the magazines, relative to each other.

In all of these areas of monitoring, careful measurements will be required to determine whether the walls are still moving or the cracks referenced in the report are continuing to grow.

Movement of the bulge east of the mining casement

For monitoring the movement of the bulge in the moat retaining wall, we recommend establishing a hard spot (i.e. the head of a bronze bolt) embedded in the face of the moat retaining wall at the bulge on the west side of the moat. Using a high precision (1/16 inch or 1.5mm) laser distance meter, measure the distance across the moat to a small target permanently mounted on the brick on the scarp, directly across the moat from the bulge. For measurement points, we generally use round head bronze screws or hexagonal head bronze bolts, four inches long and 3/8 of an inch in diameter, embedded in the tabby or the brick masonry. We recommend leaving only as much of the bolt head exposed outside of the tabby as is necessary to provide a measurement point. This generally means embedding the bolts approximately 3-1/2 inches into the tabby. The target and the bolt should both be at approximately the same elevation, approximately one to two feet above the high tide line. Measurements should be taken once a month for a year then quarterly for the next five years. The measurements should be evaluated annually.

Settlement of the east tabby retaining wall along the main pathway

Measuring settlement is slightly more involved, in that it requires either hiring a surveyor to do leveling or having a Park Service staff member who is familiar with leveling from a construction background measure the settlement of several measurement points relative to fixed points. We recommend installing bronze bolts at six to eight locations in the uppermost lift of the tabby wall and using the bolt heads as measurement points. Their elevations should be compared to the average of the elevations of at least three similar bolts installed in nearby relatively fixed points, such as the drawbridge lift mechanisms and the mining casemate door hinge, all of which are believed to be supported on piles.

Crack width measurement

Finally, measurement of the relative movement across cracks or joints between lifts or pieces of tabby or stone is relatively simple. Experience has shown that, for monitoring cracks that are exposed to the weather, plastic Avongard crack monitors are relatively ineffective. The red crosshair deteriorates in the sunlight and visitors tend to damage the monitors. Instead, we recommend installing two bronze bolts, one on each side of the crack. We recommend installing the bolts approximately 2 inches away from the crack. The bolts can be bedded in epoxy or in a hard cementitious grout in holes drilled into the tabby.

We recommend measuring the distance between the bolts with high precision calipers or a micrometer once a month during the first year of the installation, with quarterly measurements continued thereafter. Readings should be taken on approximately the same day each month. We recommend that, even if readings are recorded in spreadsheets, a paper copy of all readings be kept.

For monitoring movement of the Fort Pulaski demilune, we recommend installing approximately six pairs of monitoring bolts on the east tabby retaining wall of the main north-south pathway. We recommend installing at least two pairs of bolts at the broken stones at the tee in the centrer magazine. For the stones in the center magazine, a smaller bolt would be more appropriate.

We have considered the possibility of recommending electronic crack monitoring equipment. Linearly variable differential transformers (LVDTs) can give exceptionally precise measurements of movement, typically on the order of a few micrometers, and are especially good at recording motion in response to specific events. We at Bennett Preservation Engineering have installed electronic crack monitors at several locations. Experience has taught us that if very precise measurements of movement in response to events are necessary, these are exceptional instruments. But we have also learned that electronic crack monitoring systems are very sensitive to damage, must be waterproofed, are targets for visitors and are expensive to install and even more expensive to maintain. We are reluctant to recommend that the Park Service install electronic monitors in the demilune, and believe that embedded bolts will give the staff the necessary information at a far lower cost.

The information obtained from the installation and monitoring of these bolts will indicate to the National Park Service how severe the movement and deformation issue is and whether the rate of change of the movement is increasing or decreasing. Red flags for action would be either a slow but accelerating movement or a sudden shift in a crack. Information obtained also has the potential to permit correlation of the movement with a direct cause, if events such as seismic activity, floods, hurricanes, tornados and construction operations with the movement of heavy loads down the pathway are recorded.

If the National Park Service would like additional help or simply consultation on installation and measuring techniques, Bennett Preservation Engineering would be glad to offer input into the process.

See the following four photographs for photographs of Avongard crack monitors and of LVDT based electronic crack monitoring systems.



Figure 1: Avongard crack monitor spanning a rather large crack in the walls of an 1816 cathedral.

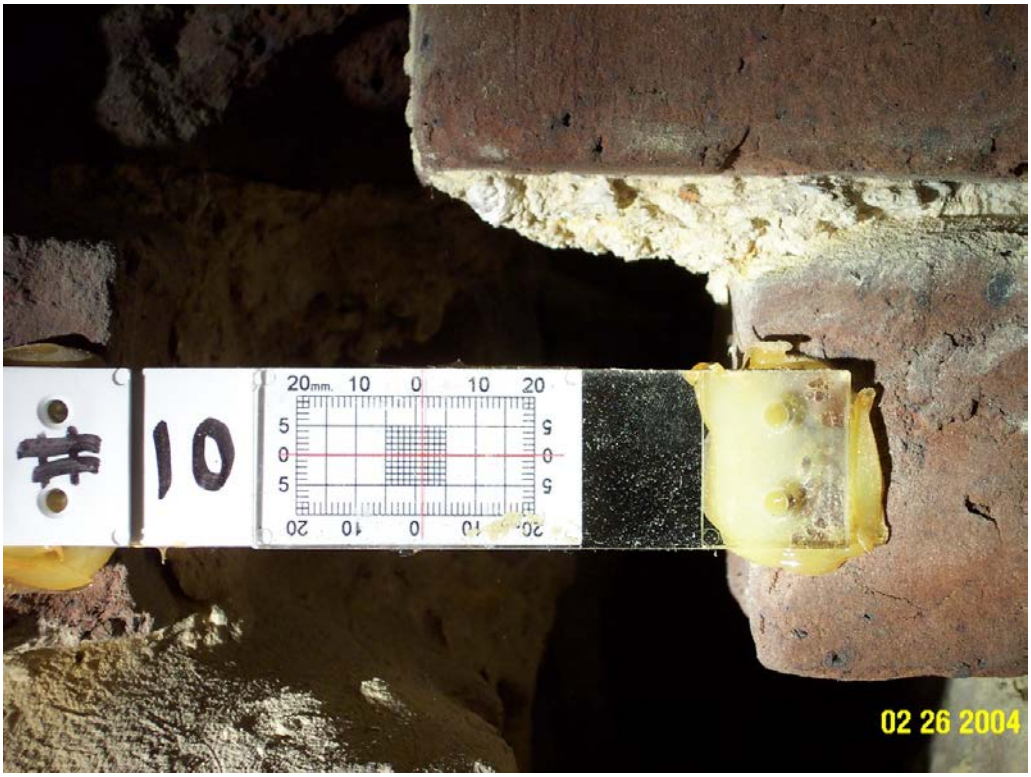


Figure 2: Same. We have found that, with care, we are able to measure movement with a precision of approximately 0.2 mm (200 micrometers.)

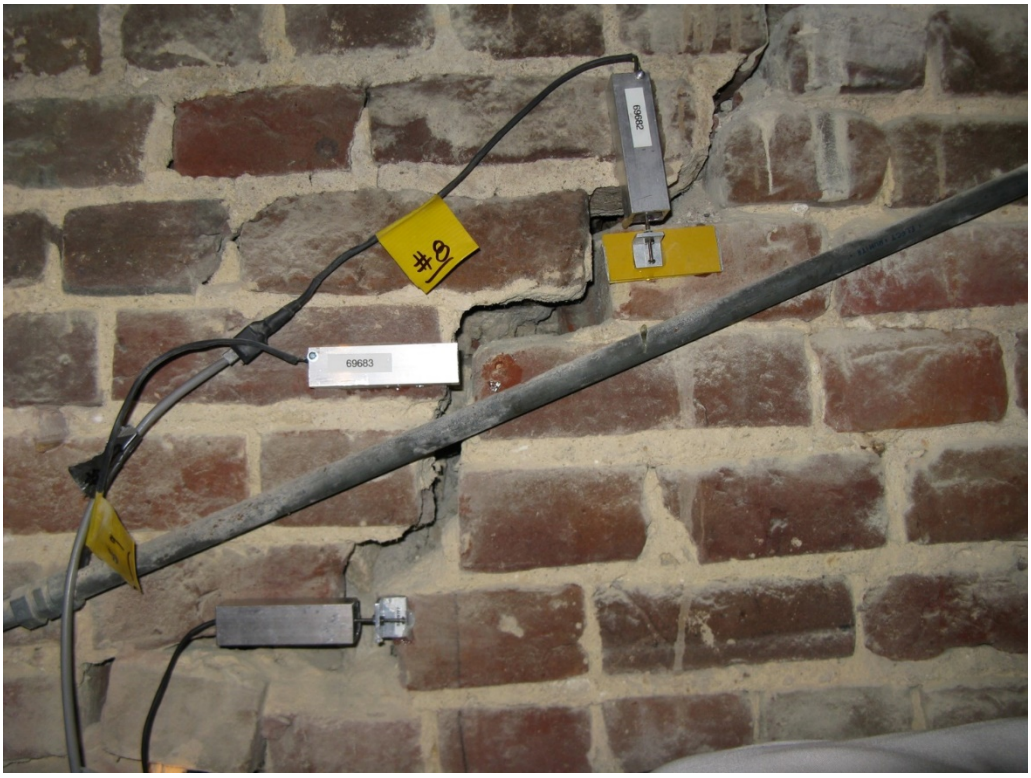


Figure 3: LVDTs spanning a crack both vertically and horizontally to monitor movement in both directions.



Figure 4: Data logger for logging data from multiple crack monitors.

We believe that all of the work recommended in this report is relatively simple and most appropriately undertaken by National Park Service staff. The supplies and equipment necessary to follow the recommendations in the report can be purchased easily and the skills necessary to take the measurements are either already within the capabilities of maintenance personnel or are easily grasped. But while the work is within staff capabilities, it is possible that staff is not available at this time for the work. For that reason, Bennett Preservation Engineering has produced two cost estimates.

The first cost estimate assumes that staff will install all of the bronze bolts and will take all of the measurements. But while most maintenance staff members are capable of drilling and installing bronze bolts and using a laser distance meter and calipers or a micrometer, it is not a given that there will be someone on the maintenance staff who will be familiar with using a builder's level and rod. If leveling is not in the skill set of the staff, it would be appropriate to engage a surveyor for initial measurements and to instruct staff in taking subsequent measurements. The total five year cost of measurements, using this approach, is approximately $6,600, with the additional requirement of 17 days of time for two staff members the first year, and 5 days per year for two staff members in subsequent years.

As we do not have National Park Service internal labor rates and, as the rates change depending on who is doing the work, we have left this cost estimate for staff time in units of time rather than money. The 272 man-hours for the first year and the 80 man-hours for each subsequent year are easily multiplied by current labor rates to find current cost. The Class C Cost Estimate for this first approach follows as the first four pages of this section.

The second cost estimate assumes that the Park Service will hire a surveyor to install the bolts, do all of the leveling, and to take all other measurements. This approach places no demands on Park Service staff, other than reading and interpreting annual reports from the surveyor. The total five year cost of measurements, using this second approach is approximately $85,000. While we are confident that there would be ways to cut costs within this pricing, we still are not comfortable that this approach is a good use of limited resources. The Class C Cost Estimate for this second approach follows as the second four pages of this section.

In summary, Bennett Preservation Engineering recommends having staff take these measurements. As outlined in the first Class C Cost Estimate provided, we recommend budgeting approximately $6,600 for all out-of-pocket costs, 17 days for two staff members for the first year, and 5 days for two staff members for each subsequent year.

The information that these measurements will provide will permit the National Park Service staff at Fort Pulaski to make well informed decisions on the need for remedial actions at the demilune.

United States Department of the Interior
National Park Service
Class C Construction Cost Estimate

BASIS OF ESTIMATE

PROJECT INFORMATION

Project:	Fort Pulaski Demilunes Monitoring Recommendations
Park:	Fort Pulaski National Monument
Park Alpha:	FOPU
PMIS Number:	PMIS 218936
Estimate Date:	16-Apr-20
Prepared By:	Taylor Frost
Company:	Bennett Preservation Engineering
Address:	17 Lockwood Suite 500
City, State Zip:	Charleston, SC 29401
Phone:	843-577-8850

BACKGROUND SUPPORTING MATERIAL (Scope of Work):

This estimate accompanies Bennett Preservation Engineering's Report on the condition of Fort Pulaski's demilunes and the recommendation for monitoring the movement of the demilune walls with monthly, then yearly measurements.

SOURCE OF COST DATA:

RS Means, local hardware stores (Home Depot, Lowes), marine supply stores (Jamestown Distributors)

ESTIMATE ASSUMPTIONS:

It assumed that the simple nature of this work can be completed by the NPS Maintenance Staff.

MAJOR CHANGES FROM PREVIOUS ESTIMATE:

N/A

United States Department of the Interior
National Park Service
Class C Construction Cost Estimate

BASIS OF ESTIMATE

PROJECT INFORMATION

Project: Fort Pulaski Demilunes Monitoring Recommendations

Park: Fort Pulaski National Monument
Park Alpha: FOPU
PMIS Number: PMIS 218936
Estimate Date: 16-Apr-20

DESCRIPTION OF MARK-UP & ADD-ONS:

Location Factor:	-15.50%	Source: RS Means
Remoteness Factor:	1.39%	Site is 13.9 miles from published commercial center. Describe other impacts included
Wage Rate Factor:	0.00%	
State & Local Taxes:	7.00%	Sales tax for Chatham County, Georgia
Design Contingency:	20.00%	Minimal changes in this scope of work expected
Standard. General Conditions:	10.00%	Standard
Government General Conditions:	10.00%	Standard
Historic Preservation Factor:	10.00%	Describe rationale for using this factor
Contractor Overhead:	0.00%	Already built-in to the surveyor's hourly rate
Contractor Profit:	0.00%	Already built-in to the surveyor's hourly rate
Bonds and Permits:	0.00%	Not nescessary
Contracting Method Adjustment:	0.00%	Describe anticipated contract method and justify value used.
Annual Inflation Escalation Factor:	3.00%	Projected annual inflation rate.
Time Until Project Midpoint (Months)	30	Assumed five years of monitoring

OTHER COMMENTS:

N/A

United States Department of the Interior
National Park Service
Class C Construction Cost Estimate

PROJECT COST SUMMARY

Project: Fort Pulaski Demilunes Monitoring Recommendations
Park: Fort Pulaski National Monument
Alpha: FOPU
PMIS: PMIS 218936

Estimate By: Taylor Frost
Date: 04/16/20

Reviewed By: Craig Bennett
Date: 04/17/20

Item No.	Description	Quantity	Unit	Cost/Unit	Total
1	Monitoring Costs with FOPU Staff Labor (5 Years)	1	VALUE	$4,170	$4,170
2	Asset / Project Element 2	1	VALUE	$0	$0
3	Asset / Project Element 3	1	VALUE	$0	$0
4	Asset / Project Element 4	1	VALUE	$0	$0
5	Asset / Project Element 5	1	VALUE	$0	$0
6	Asset / Project Element 6	1	VALUE	$0	$0
7	Asset / Project Element 7	1	VALUE	$0	$0
8	Asset / Project Element 8	1	VALUE	$0	$0
9	Asset / Project Element 9	1	VALUE	$0	$0
10	Asset / Project Element 10	1	VALUE	$0	$0
11	Asset / Project Element 11	1	VALUE	$0	$0
12	Asset / Project Element 12	1	VALUE	$0	$0
13	Not Used	1	VALUE	$0	$0
14	Not Used	1	VALUE	$0	$0
15	Not Used	1	VALUE	$0	$0
16	Not Used	1	VALUE	$0	$0
17	Not Used	1	VALUE	$0	$0
18	Not Used	1	VALUE	$0	$0
	Subtotal Direct Construction Costs				**$4,170**
	Value of Government Furnished Property (GFP) Included in Direct Cost (see footnote)*				**$0**
				Direct Cost Subtotal without GFP	**$4,170**
	Published Location Factor	-15.50%			-$646
	Remoteness Factor	1.39%			$58
	Federal Wage Rate Factor	0.00%			$0
	State & Local Taxes	7.00%			$292
	Design Contingency	20.00%			$834
	Total Direct Construction Costs				**$4,708**
	Standard General Conditions	10.00%			$471
	Government General Conditions	10.00%			$471
	Historic Preservation Factor	10.00%			$471
	Subtotal NET Construction Cost				**$6,120**
	Overhead	0.00%			$0
	Profit	0.00%			$0
	Estimated NET Construction Cost				**$6,120**
	Bonds & Permits	0.00%			**$0**
	Contracting Method Adjustment	0.00%			$0
	Inflation Escalation	30	Months	3.00%	$469
	Total Estimated NET Cost of Construction				**$6,589**

* GFP costs are only used when the Government pre-purchases items, or provides other materials out of Government inventory, to be installed by contractor. Adjustments and Markup on GFP only include Inflation Escalation; No other adjustment factors or O&P markup have been applied.

United States Department of the Interior
National Park Service
Class C Construction Cost Estimate

LINE ITEM COST SUMMARY

Project:	**Fort Pulaski Demilunes Monitoring Recommendations**	**Estimate By:**	Taylor Frost
Park:	**Fort Pulaski National Monument**	**Date:**	04/16/20
Park Alpha:	**FOPU**	**Reviewed By:**	Reviewer
PMIS Number:	**PMIS 218936**	**Date:**	Review Date
Summary Item 1	**Monitoring Costs with FOPU Staff Labor (5 Years)**	**Total Cost:**	$4,170

Uniformat II WBS Code	Description	Quantity	Unit	Cost/Unit	Total Cost	Remarks
	LABOR COST FOR MONITORING					
Level 3 Code	Surveyor for Leveling Instruction	24	Hours	$ 110.00	$2,640	
Level 3 Code	First Year Measurements	17	Days	$ -	$0	
Level 3 Code	Second Year Measurements	5	Days	$ -	$0	
Level 3 Code	Third Year Measurements	5	Days	$ -	$0	
Level 3 Code	Fourth Year Measurements	5	Days	$ -	$0	
Level 3 Code	Fifth Year Measurements	5	Days	$ -	$0	
Level 3 Code	Description	0	Unit	$ -	$0	
Level 3 Code	Description	0	Unit	$ -	$0	
	SUBTOTAL FOUNDATIONS	**1**	**VALUE**	**$ 2,640.00**	**$2,640**	

Uniformat II WBS Code	Description	Quantity	Unit	Cost/Unit	Total Cost	Remarks
	MONITORING EQUIPMENT					
Level 3 Code	Bronze Bolts	30	Unit	$ 5.00	$150	
Level 3 Code	Drill Bits	1	Unit	$ 50.00	$50	
Level 3 Code	Epoxy	1	Unit	$ 100.00	$100	
Level 3 Code	Outside Flat Micrometer	1	Unit	$ 500.00	$500	
Level 3 Code	Caliper	1	Unit	$ 100.00	$100	
Level 3 Code	Laser Distance Measurer	1	Unit	$ 200.00	$200	
Level 3 Code	Small Polycarbonate Target	1	Unit	$ 30.00	$30	
Level 3 Code	Builder's Level, Tripod, Rod	1	Unit	$ 400.00	$400	
	SUBTOTAL BASEMENT CONSTRUCTION	**1**	**VALUE**	**$ 1,530.00**	**$1,530**	

United States Department of the Interior
National Park Service
Class C Construction Cost Estimate

BASIS OF ESTIMATE

PROJECT INFORMATION

Project:	Fort Pulaski Demilunes Monitoring Recommendations
Park:	Fort Pulaski National Monument
Park Alpha:	FOPU
PMIS Number:	PMIS 218936
Estimate Date:	16-Apr-20
Prepared By:	Taylor Frost
Company:	Bennett Preservation Engineering
Address:	17 Lockwood Suite 500
City, State Zip:	Charleston, SC 29401
Phone:	843-577-8850

BACKGROUND SUPPORTING MATERIAL (Scope of Work):

This estimate accompanies Bennett Preservation Engineering's Report on the condition of Fort Pulaski's demilunes and the recommendation for monitoring the movement of the demilune walls with monthly, then yearly measurements.

SOURCE OF COST DATA:

RS Means, local hardware stores (Home Depot, Lowes), marine supply stores (Jamestown Distributors)

ESTIMATE ASSUMPTIONS:

It is assumed that an outside surveyor will be hired to complete the initial and the yearly measurements.

MAJOR CHANGES FROM PREVIOUS ESTIMATE:

N/A

United States Department of the Interior
National Park Service
Class C Construction Cost Estimate

BASIS OF ESTIMATE

PROJECT INFORMATION

Project: Fort Pulaski Demilunes Monitoring Recommendations

Park: Fort Pulaski National Monument
Park Alpha: FOPU
PMIS Number: PMIS 218936
Estimate Date: 16-Apr-20

DESCRIPTION OF MARK-UP & ADD-ONS:

Location Factor:	-15.50%	Source: RS Means
Remoteness Factor:	1.39%	Site is 13.9 miles from published commercial center. Describe other impacts included
Wage Rate Factor:	0.00%	
State & Local Taxes:	7.00%	Sales tax for Chatham County, Georgia
Design Contingency:	20.00%	Minimal changes in this scope of work expected
Standard. General Conditions:	10.00%	Standard
Government General Conditions:	10.00%	Standard
Historic Preservation Factor:	10.00%	
Contractor Overhead:	0.00%	Already built-in to the surveyor's hourly rate
Contractor Profit:	0.00%	Already built-in to the surveyor's hourly rate
Bonds and Permits:	0.00%	Not nescessary
Contracting Method Adjustment:	0.00%	
Annual Inflation Escalation Factor:	3.00%	Projected annual inflation rate.
Time Until Project Midpoint (Months)	30	Assumed five years of monitoring

OTHER COMMENTS:

N/A

United States Department of the Interior
National Park Service
Class C Construction Cost Estimate

PROJECT COST SUMMARY

Project: Fort Pulaski Demilunes Monitoring Recommendations
Park: Fort Pulaski National Monument
Alpha: FOPU
PMIS: PMIS 218936

Estimate By: Taylor Frost
Date: 04/16/20

Reviewed By: Craig Bennett
Date: 04/17/20

Item No.	Description	Quantity	Unit	Cost/Unit	Total
1	Monitoring Costs with Outside Labor (5 Years)	1	VALUE	$53,930	$53,930
2	Asset / Project Element 2	1	VALUE	$0	$0
3	Asset / Project Element 3	1	VALUE	$0	$0
4	Asset / Project Element 4	1	VALUE	$0	$0
5	Asset / Project Element 5	1	VALUE	$0	$0
6	Asset / Project Element 6	1	VALUE	$0	$0
7	Asset / Project Element 7	1	VALUE	$0	$0
8	Asset / Project Element 8	1	VALUE	$0	$0
9	Asset / Project Element 9	1	VALUE	$0	$0
10	Asset / Project Element 10	1	VALUE	$0	$0
11	Asset / Project Element 11	1	VALUE	$0	$0
12	Asset / Project Element 12	1	VALUE	$0	$0
13	Not Used	1	VALUE	$0	$0
14	Not Used	1	VALUE	$0	$0
15	Not Used	1	VALUE	$0	$0
16	Not Used	1	VALUE	$0	$0
17	Not Used	1	VALUE	$0	$0
18	Not Used	1	VALUE	$0	$0
	Subtotal Direct Construction Costs				**$53,930**
	Value of Government Furnished Property (GFP) Included in Direct Cost (see footnote)*				**$0**
				Direct Cost Subtotal without GFP	**$53,930**
	Published Location Factor	-15.50%			-$8,359
	Remoteness Factor	1.39%			$750
	Federal Wage Rate Factor	0.00%			$0
	State & Local Taxes	7.00%			$3,775
	Design Contingency	20.00%			$10,786
	Total Direct Construction Costs				**$60,882**
	Standard General Conditions	10.00%			$6,088
	Government General Conditions	10.00%			$6,088
	Historic Preservation Factor	10.00%			$6,088
	Subtotal NET Construction Cost				**$79,146**
	Overhead	0.00%			$0
	Profit	0.00%			$0
	Estimated NET Construction Cost				**$79,146**
	Bonds & Permits	0.00%			**$0**
	Contracting Method Adjustment	0.00%			$0
	Inflation Escalation	30	Months	3.00%	$6,070
	Total Estimated NET Cost of Construction				**$85,216**

* GFP costs are only used when the Government pre-purchases items, or provides other materials out of Government inventory, to be installed by contractor. Adjustments and Markup on GFP only include Inflation Escalation; No other adjustment factors or O&P markup have been applied.

United States Department of the Interior
National Park Service
Class C Construction Cost Estimate

LINE ITEM COST SUMMARY

Project:	**Fort Pulaski Demilunes Monitoring Recommendations**	**Estimate By:**	Taylor Frost
Park:	**Fort Pulaski National Monument**	**Date:**	04/16/20
Park Alpha:	**FOPU**	**Reviewed By:**	Reviewer
PMIS Number:	**PMIS 218936**	**Date:**	Review Date
Summary Item 1	**Monitoring Costs with Outside Labor (5 Years)**	**Total Cost:**	$53,930

Uniformat II WBS Code	Description	Quantity	Unit	Cost/Unit	Total Cost	Remarks
	LABOR COST FOR MONITORING					
Level 3 Code	Surveyor and Assistant for Leveling	24	Hours	$ 165.00	$3,960	
Level 3 Code	First Year Measurements	17	Days	$ 1,320.00	$22,440	
Level 3 Code	Second Year Measurements	5	Days	$ 1,320.00	$6,600	
Level 3 Code	Third Year Measurements	5	Days	$ 1,320.00	$6,600	
Level 3 Code	Fourth Year Measurements	5	Days	$ 1,320.00	$6,600	
Level 3 Code	Fifth Year Measurements	5	Days	$ 1,320.00	$6,600	
Level 3 Code	Description	0	Unit	$ -	$0	
Level 3 Code	Description	0	Unit	$ -	$0	
	SUBTOTAL FOUNDATIONS	**1**	**VALUE**	**$ 52,800.00**	**$52,800**	

Uniformat II WBS Code	Description	Quantity	Unit	Cost/Unit	Total Cost	Remarks
	MONITORING EQUIPMENT					
Level 3 Code	Bronze Bolts	30	Unit	$ 5.00	$150	
Level 3 Code	Drill Bits	1	Unit	$ 50.00	$50	
Level 3 Code	Epoxy	1	Unit	$ 100.00	$100	
Level 3 Code	Outside Flat Micrometer	1	Unit	$ 500.00	$500	
Level 3 Code	Caliper	1	Unit	$ 100.00	$100	
Level 3 Code	Laser Distance Measurer	1	Unit	$ 200.00	$200	
Level 3 Code	Small Polycarbonate Target	1	Unit	$ 30.00	$30	
Level 3 Code	Builder's Level, Tripod, Rod	0	Unit	$ 400.00	$0	
	SUBTOTAL BASEMENT CONSTRUCTION	**1**	**VALUE**	**$ 1,130.00**	**$1,130**	

The work described in the following report was done under the direction of Lord Aeck Sargent and Bennett Preservation Engineering in an effort to determine more about the characteristics of the systems supporting the east retaining wall of the north-south entry walkway and to get information on the general characteristics of the soil surrounding the demilune.

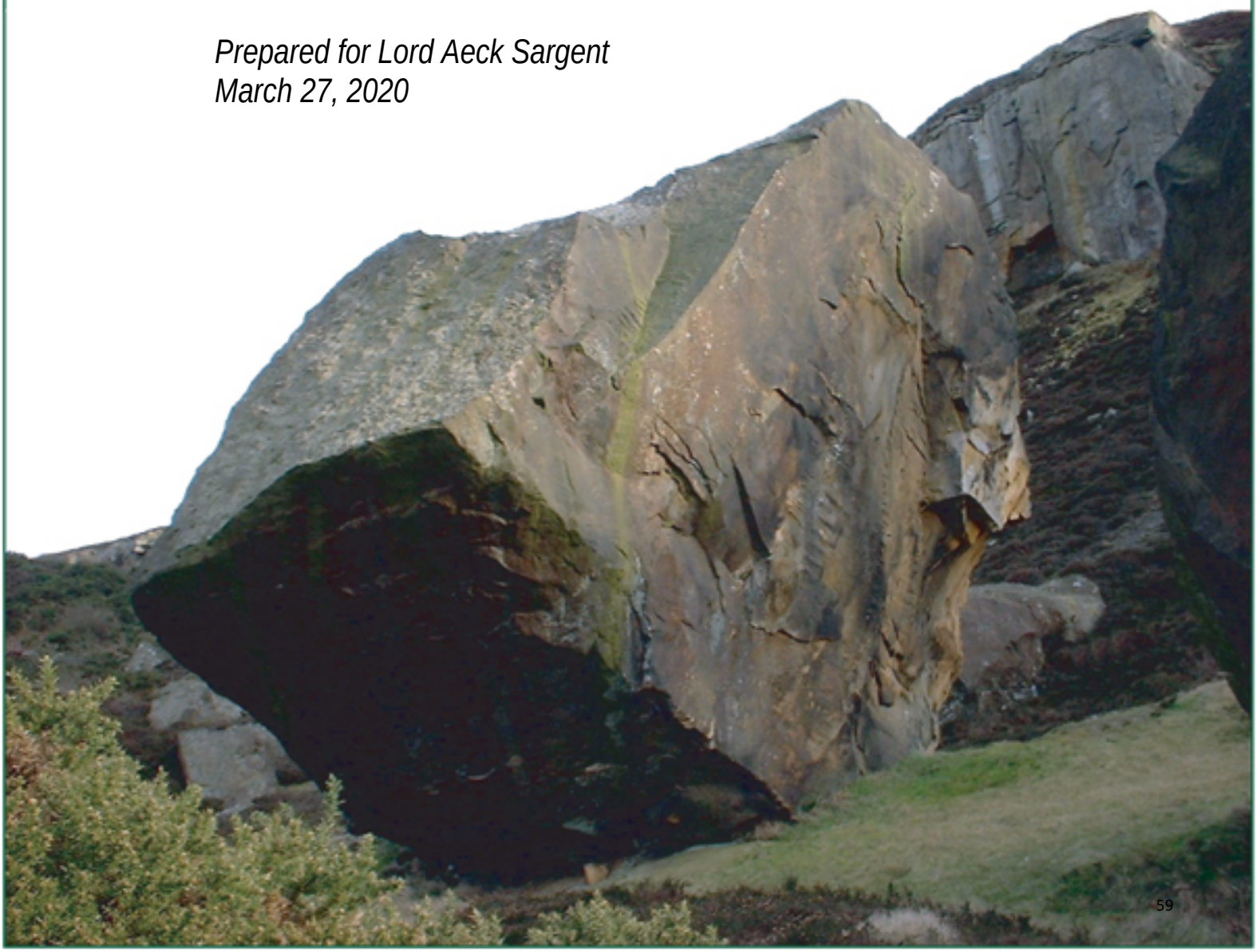
The report confirmed that only part of the whole demilune was pile-supported, confirmed that the brick masonry retaining walls are backed up by (presumably tabby concrete) walls, and confirmed that the sand layer under the demilune slopes down from north to south, with a much softer silty clay layer above.

GEO HYDRO ENGINEERS

Report of Subsurface Exploration and Geotechnical Engineering Evaluation

Demilune Retaining Walls
Fort Pulaski National Monument
Savannah, Georgia
Geo-Hydro Project Number 200181.20

Prepared for Lord Aeck Sargent
March 27, 2020



Ms. Olivia Hallquist, AIA
Lord Aeck Sargent
1175 Peachtree Street, Suite 2400
Atlanta, Georgia 30361

March 27, 2020

Report of Subsurface Exploration
and Geotechnical Engineering Evaluation
Demilune Retaining Walls
Fort Pulaski National Monument
Savannah, Georgia
Geo-Hydro Project Number 200181.20

Dear Ms. Hallquist:

Geo-Hydro Engineers, Inc. has completed the authorized subsurface exploration for the above referenced project. The scope of services for this project was outlined in our proposal number 23586.2 REV 1 dated July 24, 2019.

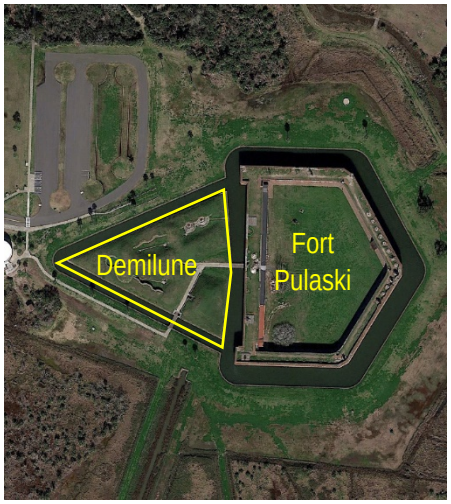
Project Information

Fort Pulaski National Monument is located on Cockspur Island in the Savannah River estuary about 12 miles east of Savannah, Georgia. Figure 1 in the Appendix shows the approximate site location.

The project concerns historic retaining walls within the demilune. The demilune is a complex of earthen structures over buried magazines just west of Fort Pulaski. The annotated aerial photograph below shows the demilune and its relationship to Fort Pulaski. Specifically, the project concerns two retaining walls constructed in the late 19th century. The walls are generally about 3 to 4 feet tall and constructed with tabby.

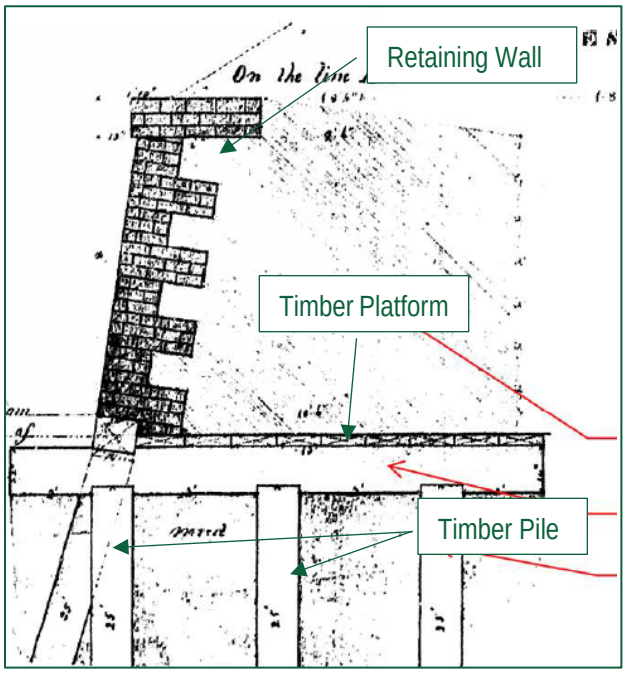
The walls contain numerous horizontal and vertical cracks along their length. The east wall is more deteriorated, with some cracks as wide as 2 inches. Cracking has also been observed within the tabby magazines beneath the earthen structures, and we understand that the cracking and deterioration has accelerated over the last 3 years.



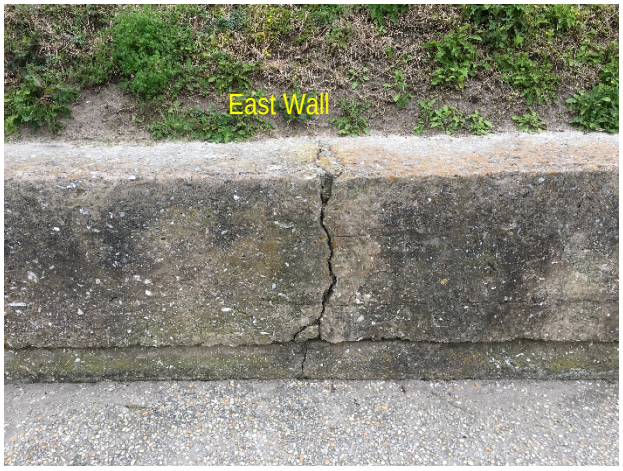


We understand that the walls are supported on a timber platform, which is supported on timber piles. The wall cross section to the right was provided to us and shows the wall support system. The photographs below show the condition of the walls at the time of our exploration.













EXPLORATORY PROCEDURES

The subsurface exploration consisted of four hand auger borings and three cone penetration test (CPT) soundings performed at the approximate requested locations shown on Figure 2 included in the Appendix. The borings were located in the field by measuring angles and distances from existing site features. In general, the locations of the borings should be considered approximate.

Cone penetration testing was performed in general accordance with ASTM D5778 using an electronic cone penetrometer with type 2 porous filter location. A truck-mounted hydraulic pushing system was used to produce the soundings. Continuous measurements of tip resistance, sleeve friction, and penetration pore water pressures were recorded during a constant rate push of about 2 centimeters per second. At select depths in sounding CPT-3, a surface source was used to generate a transient signal that was recorded at depth by a geophone mounted in the penetrometer. This allowed for the determination of downhole shear wave velocities.

Dynamic cone penetrometer testing (ASTM STP-399) was performed at select depths in the hand auger borings. Soil samples obtained from the hand auger borings were examined and classified in general accordance with ASTM D2488 (Visual-Manual Procedure for Description of Soils). Soil classifications include the use of the Unified Soil Classification System described in ASTM D2487 (Classification of Soils for Engineering Purposes). The soil classifications also include our evaluation of the geologic origin of the soils. Evaluations of geologic origin are based on our experience and interpretation and may be subject to some degree of error. Descriptions of the soils encountered in the hand auger borings are provided in hand auger logs included in the Appendix. Groundwater levels and other pertinent information are also included.

For each CPT sounding, logs presenting measurements for the total cone tip resistance, pore pressure, friction ratio, shear wave velocity (where applicable), soil behavior type, and estimated standard penetration test (SPT) behavior are included in the Appendix.

REGIONAL GEOLOGY

The project site is located in the Coastal Plain geologic province of Georgia. The soils comprising the Coastal Plain include a complex mixture of unconsolidated to weakly indurated sediments consisting of sands, silts, clays and associated carbonate deposits. In upland areas, soil profiles consist of sands, silts, and clays that for the most part are unchanged since deposition. Where limestone or other carbonate rock is present, soil profiles typically consist of a residuum formed by the solutioning of the parent material. In lowland areas, surficial soils are typically recent and are characterized by the presence of highly organic deposits associated with flood plains, marshes and swamps.

SUBSURFACE EXPLORATION SUMMARY

Hand Auger Borings

Starting at the ground surface, all of the borings encountered approximately 3 to 4 inches of topsoil. Topsoil thicknesses should be expected to vary, and measurements necessary for detailed quantity estimation were not performed for this report.

Beneath the topsoil, all of the borings encountered fill materials extending to the depth of hand auger refusal or boring termination. The fill was classified as silty clay and sand with varying amounts of oyster shells, brick fragments, glass, organic material, and other debris. Dynamic cone penetration resistances recorded in the fill ranged from 2 to greater than 25 blows per increment.

Borings H-1, H-2, and H-4 encountered conditions causing auger refusal at depths ranging from about 3 to 6 feet. Although the precise cause of auger refusal could not be determined, the conditions were consistent with large brick fragments or other hard inclusion within the fill mass. No timber fragments consistent with the timber platform supporting the demilune were encountered in the hand auger borings.

At the time of drilling, groundwater was encountered in boring H-4 at a depth of about 2 feet. No groundwater was encountered in the remaining borings at the time of our exploration. It should be noted that groundwater levels will fluctuate depending on climatic and seasonal rainfall variations and other factors and may rise in the future. Perched groundwater will be highly variable, as its presence will be predominately a function of recent rainfall. We expect the stabilized groundwater level to be consistent with the water level in the surrounding moat.

For more detailed descriptions of subsurface soil conditions, please refer to the hand auger logs included in the Appendix.

Cone Penetration Test Borings

In general, the CPT soundings show soil behavior types consisting of an upper layer of soft clay with some organic layers extending to depths ranging from about 15 feet to 25 feet. This is followed by alternating layers of various material types including sand, silt, and clay extending to termination depths ranging from 40 to 50 feet.

Groundwater levels were interpolated from the porewater pressure readings and estimated at a depth of about 2 feet below the ground surface in all of the CPT locations. It should be noted that groundwater levels will fluctuate depending on yearly and seasonal rainfall variations and other factors and may rise in the future. We expect the stabilized groundwater level to be consistent with the water level in the surrounding moat.

The Appendix contains detailed CPT sounding logs and interpreted soil properties for each sounding. Each sounding log presents measurements for the total cone tip resistance, pore pressure, and sleeve friction, as

well as derived soil behavior types and estimated equivalent standard penetration test resistances (ASTM D1586).

EVALUATIONS AND RECOMMENDATIONS

The following evaluations and recommendations are based on the information available on the existing structure, the data obtained from the exploration, and our experience with soils and subsurface conditions similar to those encountered at this site. Because the testing represents a very small statistical sampling of subsurface conditions, it is possible that conditions different from those indicated by the hand auger logs and CPT soundings may be present beneath the demilune.

Geotechnical Considerations

In general, the hand auger borings indicate that the soil retained by the tabby walls consists of loose sand and soft clays containing oyster shells, brick fragments, and other debris. The *Earth Pressure* section of this report contains recommended earth pressure coefficients to model the load exerted on the walls by the retained soil.

The CPT soundings suggest that the demilune is underlain by about 15 to 25 feet of generally soft clay with some organic layers. Beneath this upper layer, the CPT soundings encountered various soil types that appear capable of providing support for the timber piles installed beneath the demilune. It does not appear that the recent cracking observed in the tabby magazines or retaining walls is related to the underlying soil's ability to support the timber piles. However, the cross-sectional dimensions and depth of the piles is not known.

Potential causes of the observed cracking include deterioration of the tabby material itself, which may result in a loss of structural integrity within the wall itself as the lifts of tabby lose their structural connection. Other potential causes of the cracking include deterioration of the underlying timber platform and/or timber piles, which would compromise vertical support of the retaining walls. To further evaluate potential mechanisms for the recent acceleration of cracking in the retaining walls, a monitoring program to record vertical and horizontal displacements at select locations along the wall would provide valuable information. At each location along the wall, the horizontal and vertical position at the top, middle, and bottom of the wall should be recorded.

Based on the results of the CPT soundings, the demilune is underlain by an initial layer of soft clay extending to a depth of 15 to 25 feet, which is underlain by a relatively competent layer consisting of several soil types that is capable of supporting the demilune retaining walls if the load can be adequately transferred to the underlying layer. If it is determined that the timber mat or timber piles are no longer adequately supporting the walls, options for underpinning the walls will depend on the condition of the timber mat and piles. It will also depend on the layout of the piles and timber mat. If it becomes necessary to develop an underpinning solution, it may be necessary to perform a test pit exploration to evaluate the condition of the underlying timber structure and determine the spatial arrangement of the mat and piles.

Earth Pressure

Three earth pressure conditions are generally considered for retaining wall design or evaluation: "at rest", "active", and "passive" stress conditions. Retaining walls which are rigidly restrained at the top and will be essentially unable to rotate under the action of earth pressure (such loading dock walls) should be designed for "at rest" conditions. Retaining walls which can move outward at the top as much as 0.5 percent of the wall height (such as free-standing walls) should be designed for "active" conditions. For the evaluation of the resistance of soil to lateral loads the "passive" earth pressure must be calculated. It should be noted that full development of passive pressure requires deflections toward the soil mass on the order of l.0 percent to 4.0 percent of total wall height.

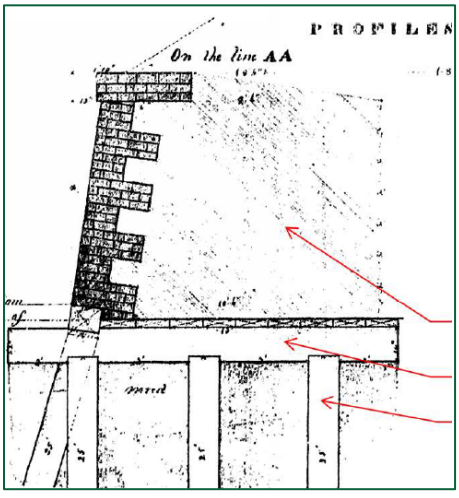
Earth pressure may be evaluated using the following equation:

$$p_h = K (D_w Z + q_s) + W_w(Z-d)$$

where: p_h = horizontal earth pressure at any depth below the ground surface (Z).
W_w = unit weight of water
Z = depth to any point below the ground surface
d = depth to groundwater surface
D_w = wet unit weight of the soil backfill (depending on borrow sources). The wet unit weight of most native soils may be expected to range from approximately 115 to 125 pcf. Below the groundwater level, D_w must be the buoyant weight.
q_s = uniform surcharge load (add equivalent uniform surcharge to account for construction equipment loads)
K = earth pressure coefficient as follows:

Earth Pressure Condition*	Coefficient
Active (K_a)	0.8

*In the case of the demilune retaining walls, only the “active” stress condition applies. Considering the cross-section detail to the right, which shows the timber platform and timber piles, lateral loads are resisted primarily by the platform via the vertical and battered piles, with possible contribution by the floor between the walls.



The groundwater term, $W_w(Z-d)$, should be used if no drainage system is incorporated behind below-grade structures. If a drainage system is included which will not allow the development of any water pressure behind the below-grade structure, then the groundwater term may be omitted. The development of excessive water pressure is a common cause of retaining wall failures. Drainage systems should be carefully designed to ensure that long term permanent drainage is accomplished.

For convenience, equivalent fluid densities are frequently used for the calculation of lateral earth pressures. For the "active" state of stress, an equivalent fluid density of 96 pcf may be used. This equivalent fluid density is based on the assumption that drainage behind the retaining wall will allow *no* development of hydrostatic pressure. The hand auger borings suggest that groundwater is not present behind the walls. If a temporary hydrostatic level is considered, the pressure behind the walls will increase.

For analysis of sliding resistance of the base of a cast-in-place concrete or tabby structure, the coefficient of friction may be taken as 0.5 to analyze the tabby wall supported directly on the timber platform. This is an ultimate value, and an adequate factor of safety should be used in design. The force which resists base sliding is calculated by multiplying the normal force on the base by the coefficient of friction. Full development of the frictional force could require deflection of the base of roughly 0.l to 0.3 inches.

* * * * *

We appreciate the opportunity to serve as your geotechnical consultant for this project. If you have any questions concerning this report or any of our services, please call us.

Sincerely,

GEO-HYDRO ENGINEERS, INC.



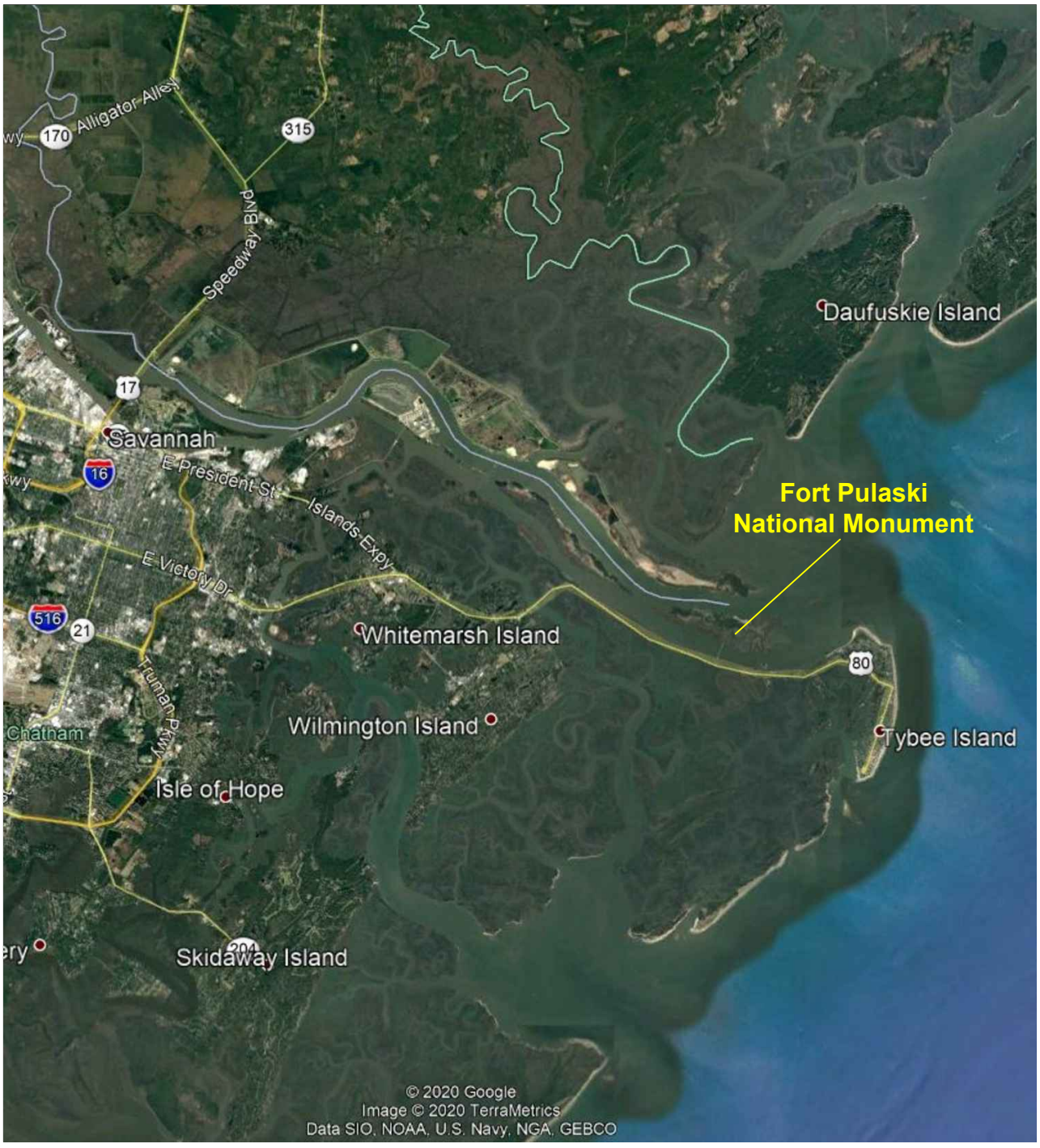


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AMP/LEB/Geo-Hydro - 200181.20 - Fort Pulaski Demilune Retaining Walls - Geotechnical Report leb

APPENDIX

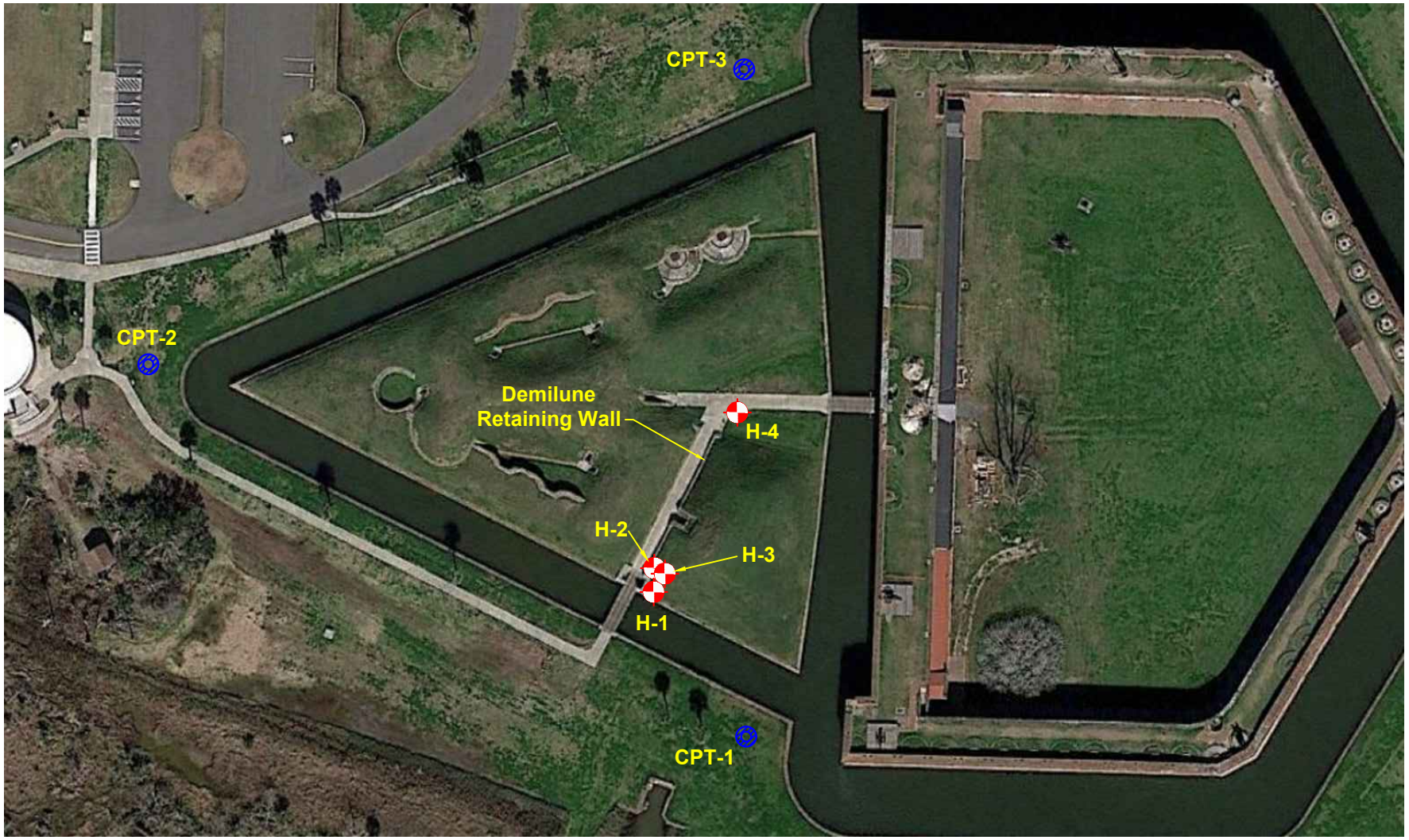


0 1.5 3 6 9

Approximate Scale, Miles

Figure 1: Site Location Plan

Demilune Retaining Walls
Fort Pulaski National Monument
Savannah, Georgia
Geo-Hydro Project Number 200181.20



0 50 100 200 300

Approximate Scale: 1"=100'

LEGEND: Hand Auger Boring
CPT Sounding

Figure 2: Test Location Plan

Demilune Retaining Walls
Fort Pulaski National Monument
Savannah, Georgia
Geo-Hydro Project Number 200181.20

HAND AUGER LOG H-1

Date Performed: 3/3/20 Logged by: AMP

Equipment: Hand Auger and Penetrometer Elevation(ft): _____

GEO HYDRO ENGINEERS

DEPTH (feet)	GRAPHIC LOG	MATERIAL DESCRIPTION	SAMPLE	PEN. RESIST	MOISTURE CONTENT (%)	DRY UNIT WT. (pcf)	LAB TESTS
0		Topsoil (Approximately 4 inches)		3			
1		Gray and orange silty clay (CL) with oyster shells (FILL)		6			
2							
3				3			
4		Gray silty clay (CH) with rock and shell fragments (FILL)					
5				4			
6		Hand Auger Refusal at 6 feet					
7		No Groundwater Encountered					
8							
9							
10							
11							

HAND AUGER LOG H-2

Date Performed: 3/3/20 Logged by: AMP

Equipment: Hand Auger and Penetrometer Elevation(ft): _____

DEPTH (feet)	GRAPHIC LOG	MATERIAL DESCRIPTION	SAMPLE	PEN. RESIST	MOISTURE CONTENT (%)	DRY UNIT WT. (pcf)	LAB TESTS
0		Topsoil (Approximately 4 inches)		2			
1		Dark gray fine sand (SP) (FILL)		3			
2							
3		Dark gray fine sand (SP) with debris (FILL)		3			
4		Hand Auger Refusal at 3 feet 6 inches		>25			
5		No Groundwater Encountered					
6							
7							
8							
9							
10							
11							

Penetration resistance was evaluated in accordance with ASTM STP-399. The penetration resistance is the number of blows of a hammer weighing 15 lbs. falling 20 inches to drive a 1.5 inch diameter cone 1.75 inches.

Demilune Retaining Walls - Fort Pulaski National Monument
Savannah, Georgia
200181.20

HAND AUGER FORT PULASKI HA LOGS.GPJ LOG A GNNN07.GDT 3/26/20

HAND AUGER LOG H-3

Date Performed: 3/3/20 Logged by: AMP

Equipment: Hand Auger and Penetrometer Elevation(ft): _____

GEO HYDRO ENGINEERS

DEPTH (feet)	GRAPHIC LOG	MATERIAL DESCRIPTION	SAMPLE	PEN. RESIST	MOISTURE CONTENT (%)	DRY UNIT WT. (pcf)	LAB TESTS
		Topsoil (Approximately 3 inches)		3			
1		Tan and gray fine sand (SP) with oyster shells, brick, and glass starting at 3 feet (FILL)		3			
2							
3				5			
4							
5				3			
6							
7							
8		Dark gray silty clay (CH) (FILL)		3			
9							
10		Boring Terminated at 10 feet		3			
11		No Groundwater Encountered					

HAND AUGER LOG H-4

Date Performed: 3/3/20 Logged by: AMP

Equipment: Hand Auger and Penetrometer Elevation(ft): _____

DEPTH (feet)	GRAPHIC LOG	MATERIAL DESCRIPTION	SAMPLE	PEN. RESIST	MOISTURE CONTENT (%)	DRY UNIT WT. (pcf)	LAB TESTS
		Topsoil (Approximately 3 inches)		5			
1		Black silty fine sand (SM) (FILL)		3			
2		Light gray and brown fine sand (SP) with clay layers (FILL)		17			
3		Dark gray silty clay (CH) with organic materials (FILL)		>25			
4		Hand Auger Refusal at 3 feet 2 inches Groundwater Encountered at 2 feet					
5							
6							
7							
8							
9							
10							
11							

Penetration resistance was evaluated in accordance with ASTM STP-399. The penetration resistance is the number of blows of a hammer weighing 15 lbs. falling 20 inches to drive a 1.5 inch diameter cone 1.75 inches.

Demilune Retaining Walls - Fort Pulaski National Monument
Savannah, Georgia
200181.20

HAND AUGER FORT PULASKI HA LOGS.GPJ LOG A GNNN07.GDT 3/26/20

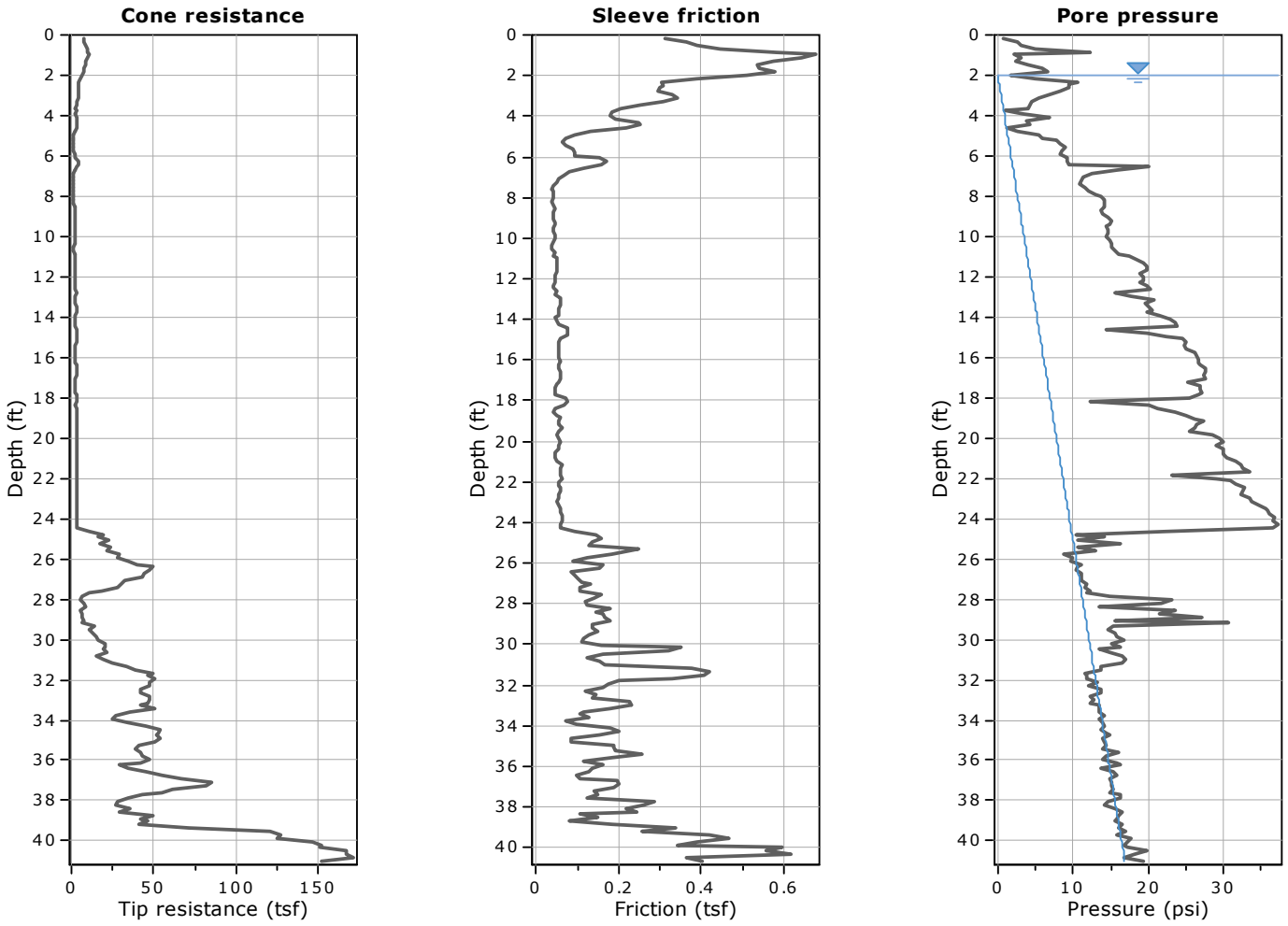
CPT SOUNDINGS

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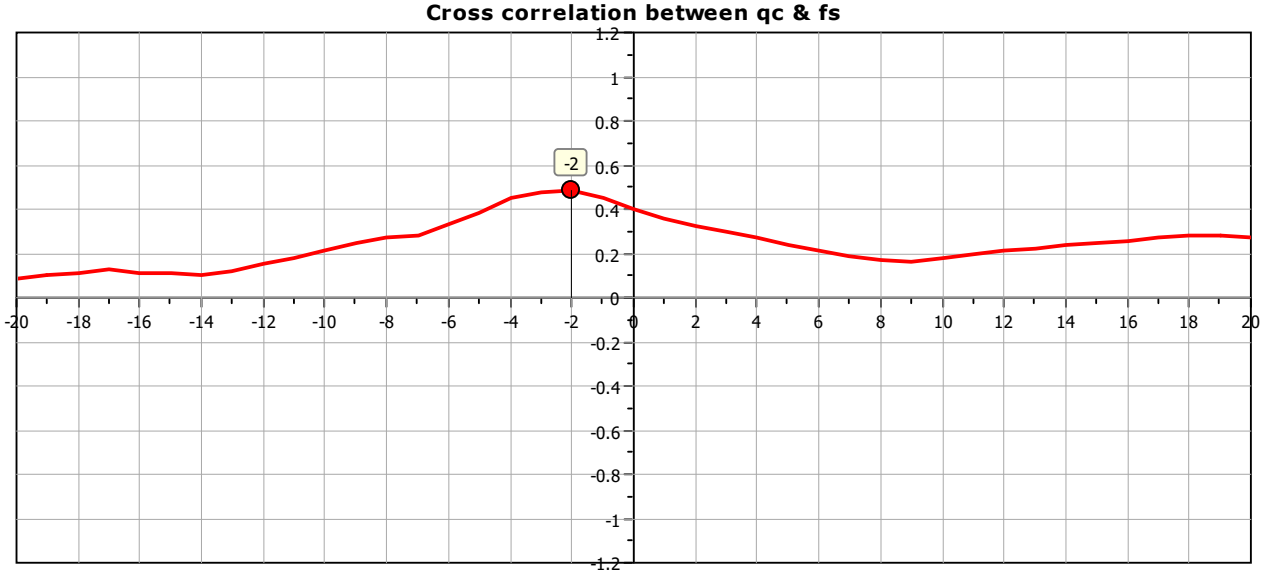
CPT: CPT-1

Project: **Fort Pulaski Demilune Retaining Walls**
Location: **Savannah, Georgia**

Total depth: 41.01 ft, Date: 3/3/2020
Cone Operator: Whitaker Laboratory, Inc.



The plot below presents the cross correlation coeficient between the raw qc and fs values (as measured on the field). X axes presents the lag distance (one lag is the distance between two sucessive CPT measurements).

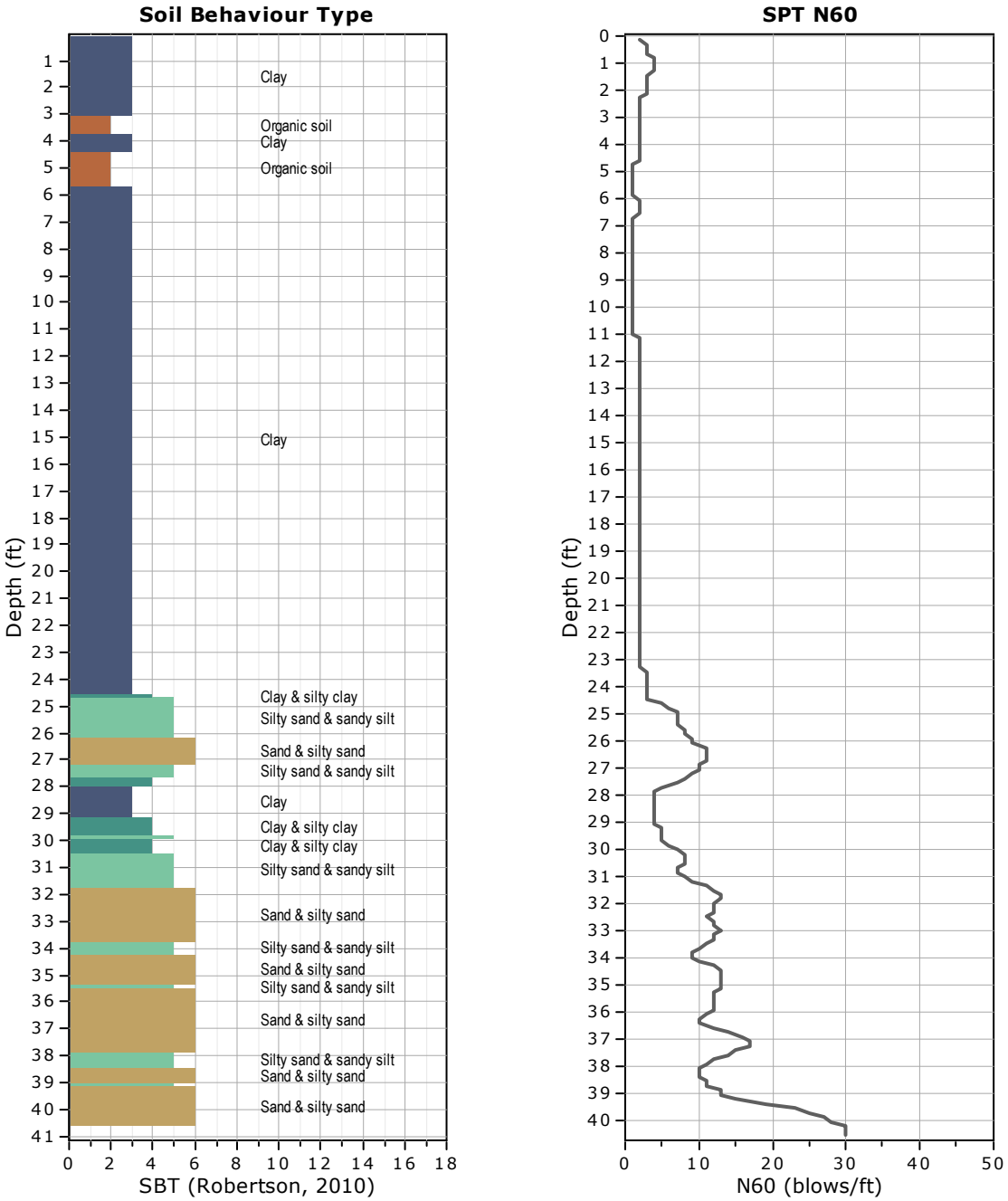


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CPT: CPT-1

Project: **Fort Pulaski Demilune Retaining Walls**
Location: **Savannah, Georgia**

Total depth: 41.01 ft, Date: 3/3/2020
Cone Operator: Whitaker Laboratory, Inc.



SBTn legend

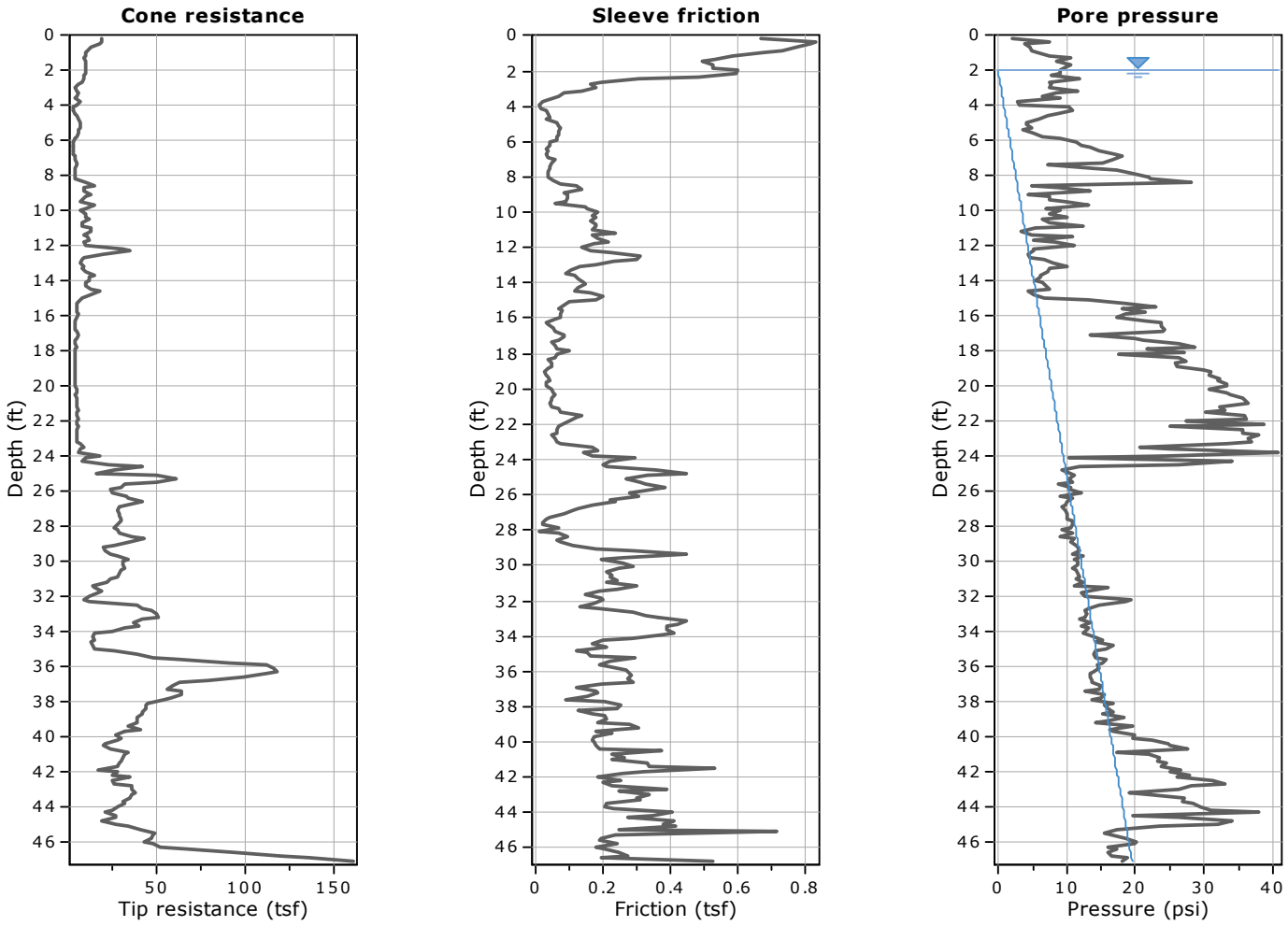
- 1. Sensitive fine grained
- 2. Organic material
- 3. Clay to silty clay
- 4. Clayey silt to silty clay
- 5. Silty sand to sandy silt
- 6. Clean sand to silty sand
- 7. Gravely sand to sand
- 8. Very stiff sand to clayey sand
- 9. Very stiff fine grained

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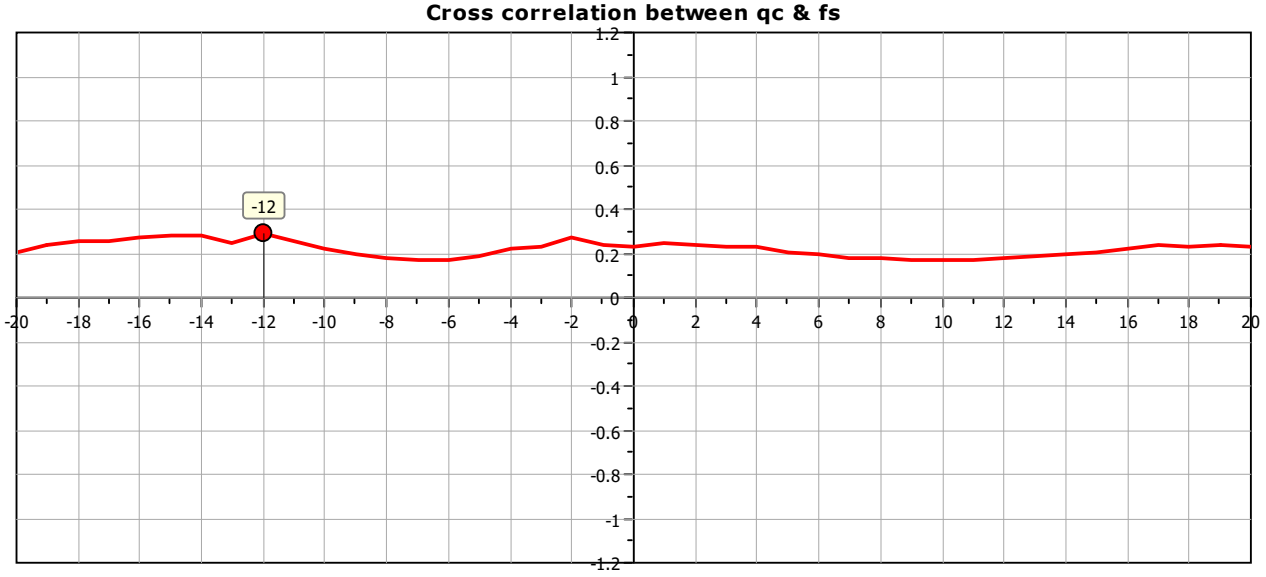
CPT: CPT-2

Project: **Fort Pulaski Demilune Retaining Walls**
Location: **Savannah, Georgia**

Total depth: 47.08 ft, Date: 3/3/2020
Cone Operator: Whitaker Laboratories, Inc.



The plot below presents the cross correlation coeficient between the raw qc and fs values (as measured on the field). X axes presents the lag distance (one lag is the distance between two sucessive CPT measurements).

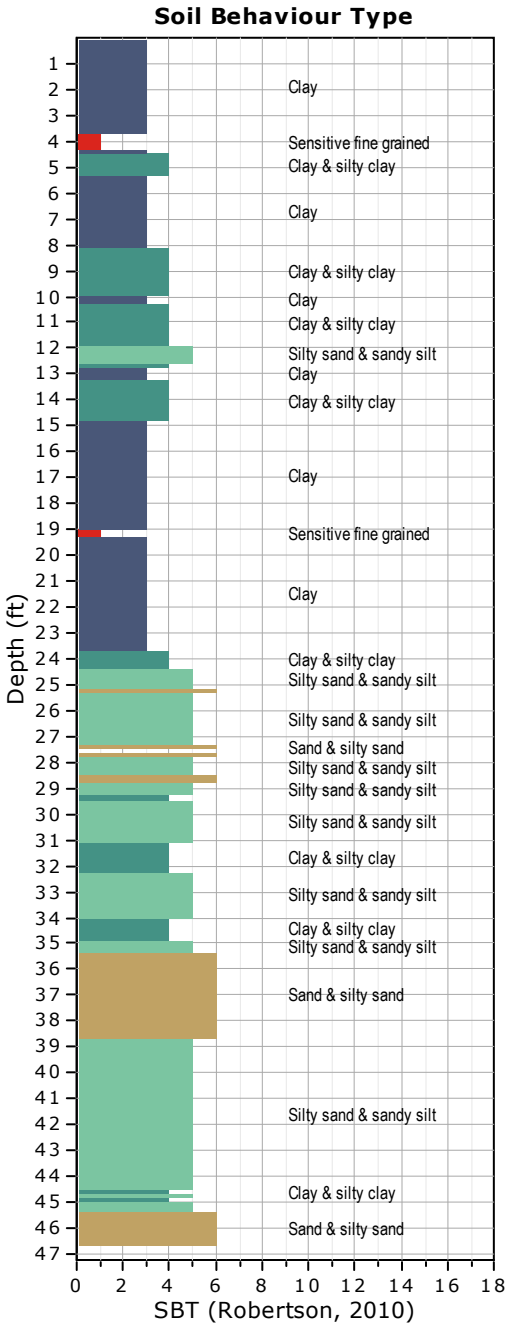


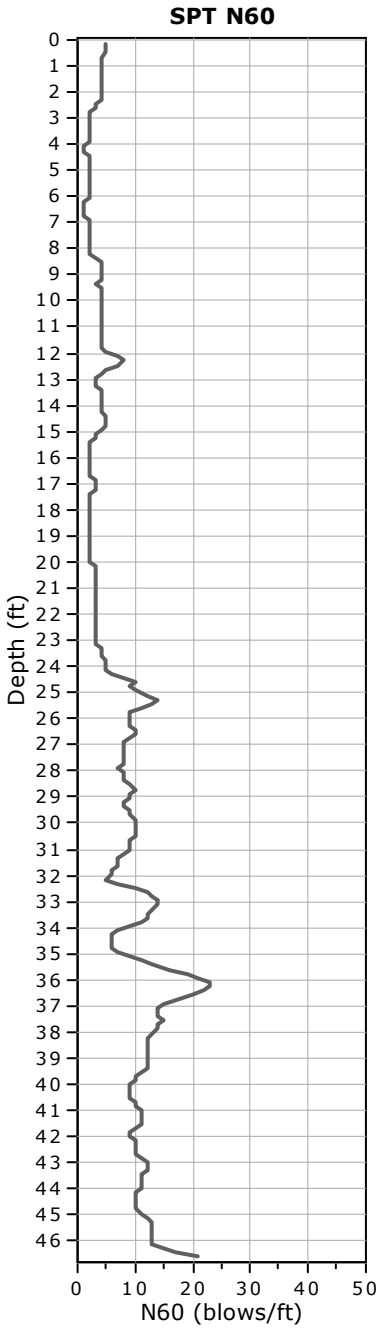
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Kennesaw, Georgia 30144
www.geohydro.com

CPT: CPT-2

Project: **Fort Pulaski Demilune Retaining Walls**
Location: **Savannah, Georgia**

Total depth: 47.08 ft, Date: 3/3/2020
Cone Operator: Whitaker Laboratories, Inc.





SBTn legend

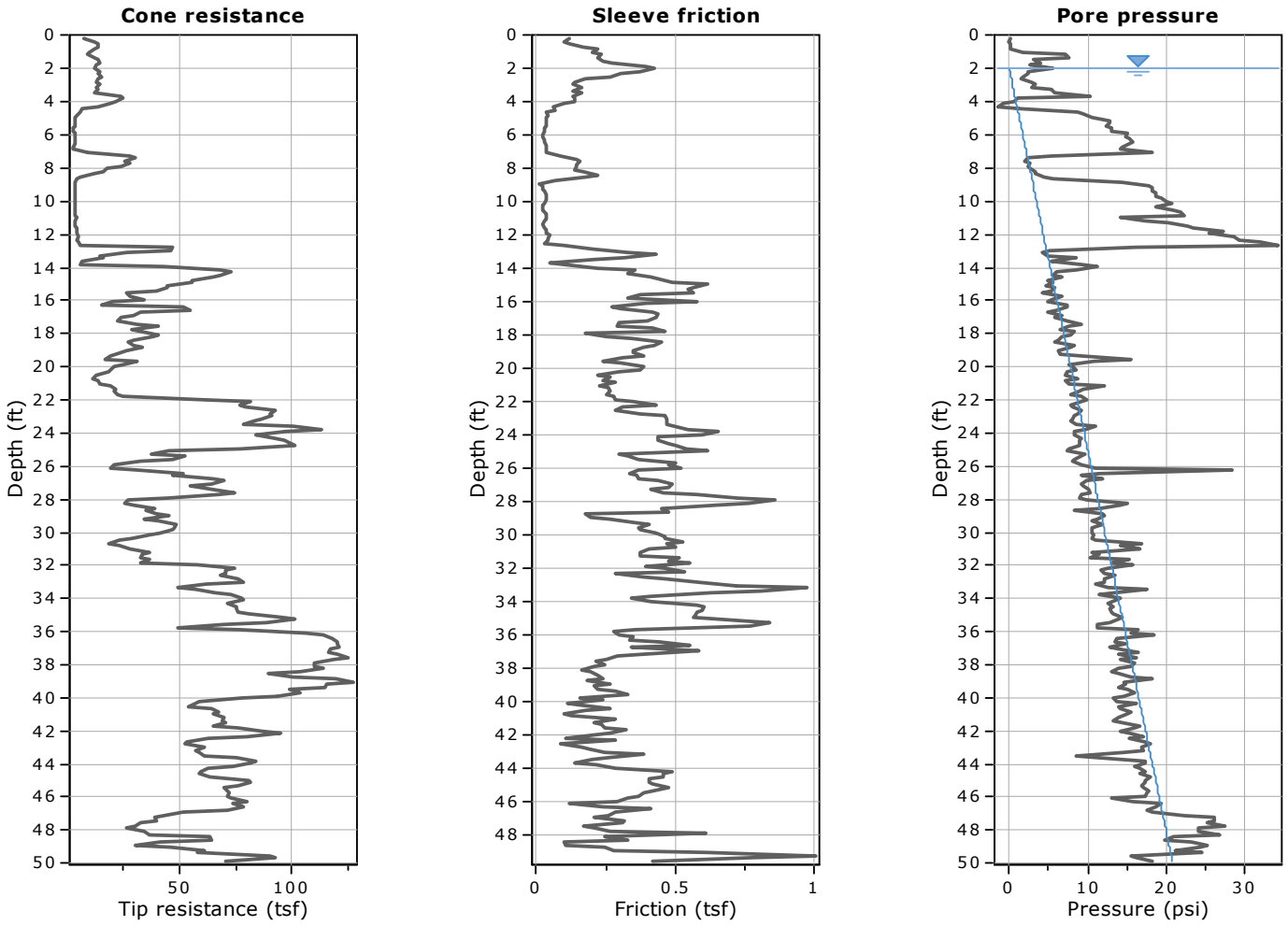
1. Sensitive fine grained	4. Clayey silt to silty clay	7. Gravely sand to sand
2. Organic material	5. Silty sand to sandy silt	8. Very stiff sand to clayey sand
3. Clay to silty clay	6. Clean sand to silty sand	9. Very stiff fine grained

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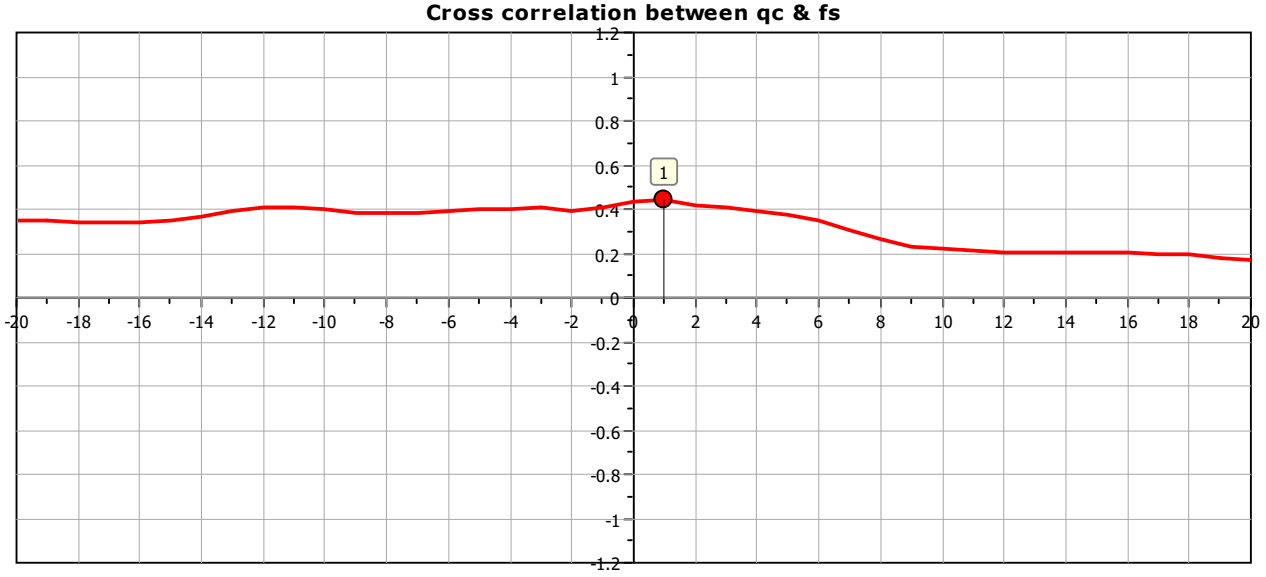
CPT: CPT-3

Project: **Fort Pulaski Demilune Retaining Walls**
Location: **Savannah, Georgia**

Total depth: 49.87 ft, Date: 3/3/2020
Cone Operator: Whitaker Laboratories, Inc.



The plot below presents the cross correlation coeficient between the raw qc and fs values (as measured on the field). X axes presents the lag distance (one lag is the distance between two sucessive CPT measurements).

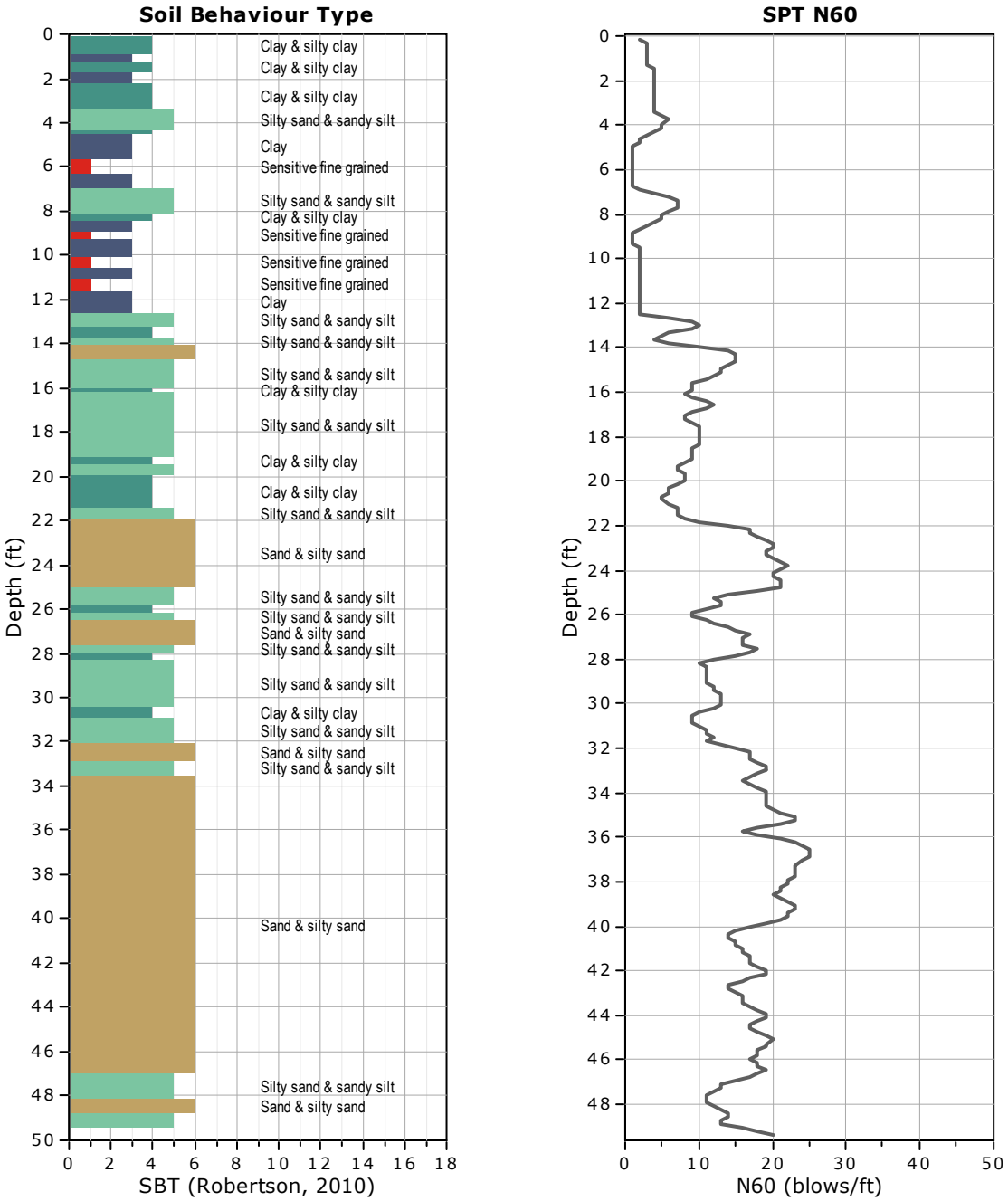


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CPT: CPT-3

Project: **Fort Pulaski Demilune Retaining Walls**
Location: **Savannah, Georgia**

Total depth: 49.87 ft, Date: 3/3/2020
Cone Operator: Whitaker Laboratories, Inc.



SBTn legend

1. Sensitive fine grained	4. Clayey silt to silty clay	7. Gravely sand to sand
2. Organic material	5. Silty sand to sandy silt	8. Very stiff sand to clayey sand
3. Clay to silty clay	6. Clean sand to silty sand	9. Very stiff fine grained

APPENDIX G – SUPPLEMENTARY PHOTOS ADDED IN RESPONSE TO NPS REVIEW

These photos provide additional information on topics added in response to National Park Service reviewer comments.



Figure 1: Diagonal lines in the tabby in the north side of the Center Magazine at Bay 1.



Figure 2: Diagonal lines in the tabby in the north side of the Center Magazine at Bay 1.



Figure 3: Diagonal lines in the tabby in the north side of the Center Magazine at Bay 1.



Figure 4: Diagonal lines in the tabby in the north side of the Center Magazine at Bay 1.



Figure 5: Diagonal lines in the tabby in the north side of the Center Magazine at Bay 1.



Figure 6: Diagonal lines in the tabby in the north side of the Center Magazine at Bay 1.



Figure 7: Similar lines on the east wall of the North Magazine.



Figure 8: Cracking in the granite quoins at the west side of the door into the Center Magazine.



Figure 9: Cracking in the granite quoins at the west side of the door into the Center Magazine.

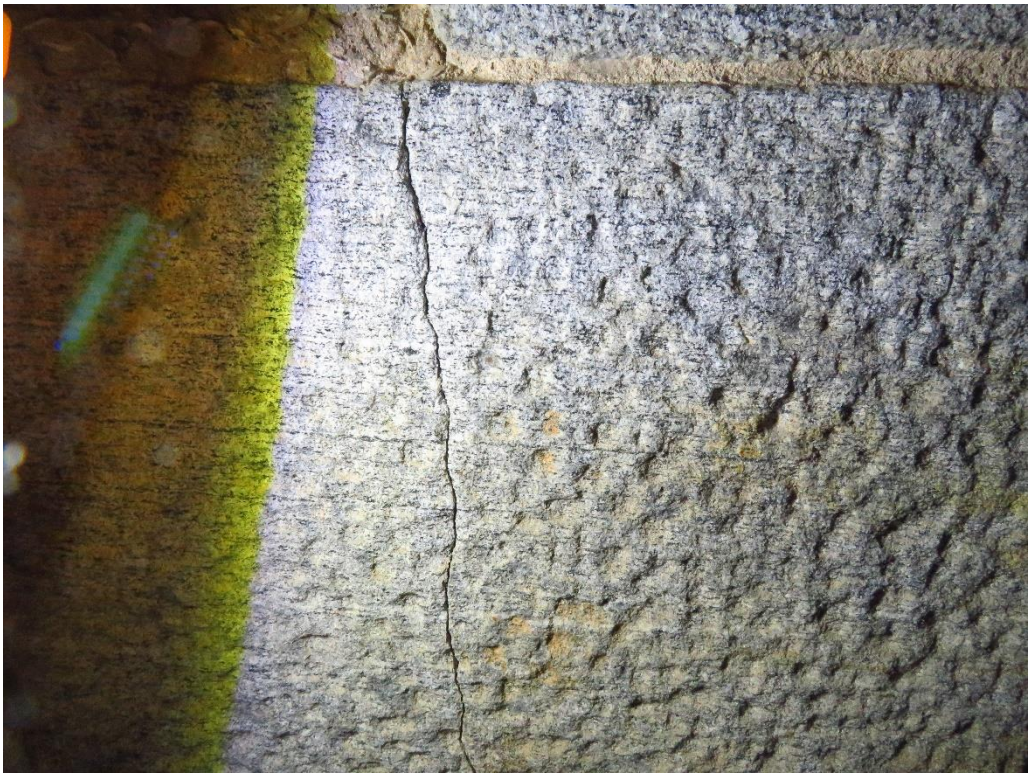


Figure 10: Cracking in the granite quoins at the west side of the door into the Center Magazine.



Figure 11: Fine cracking in the west retaining wall along the main north-south pathway.



Figure 12: Fine cracking in the west retaining wall along the main north-south pathway.

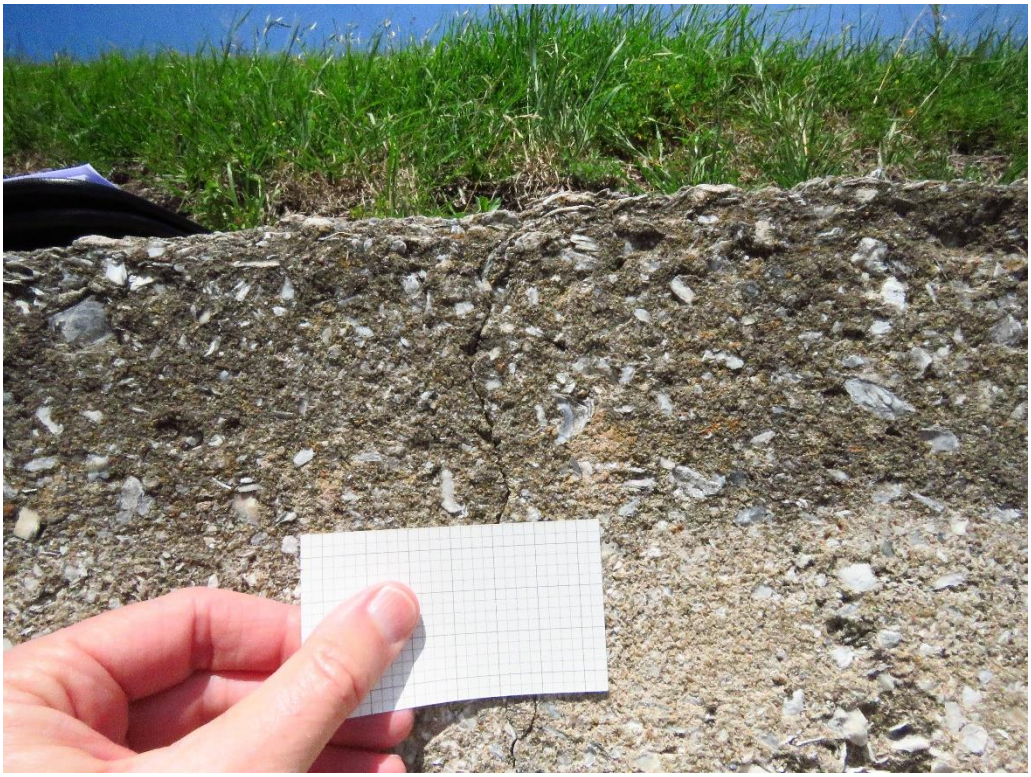


Figure 13: Fine cracking in the west retaining wall along the main north-south pathway.

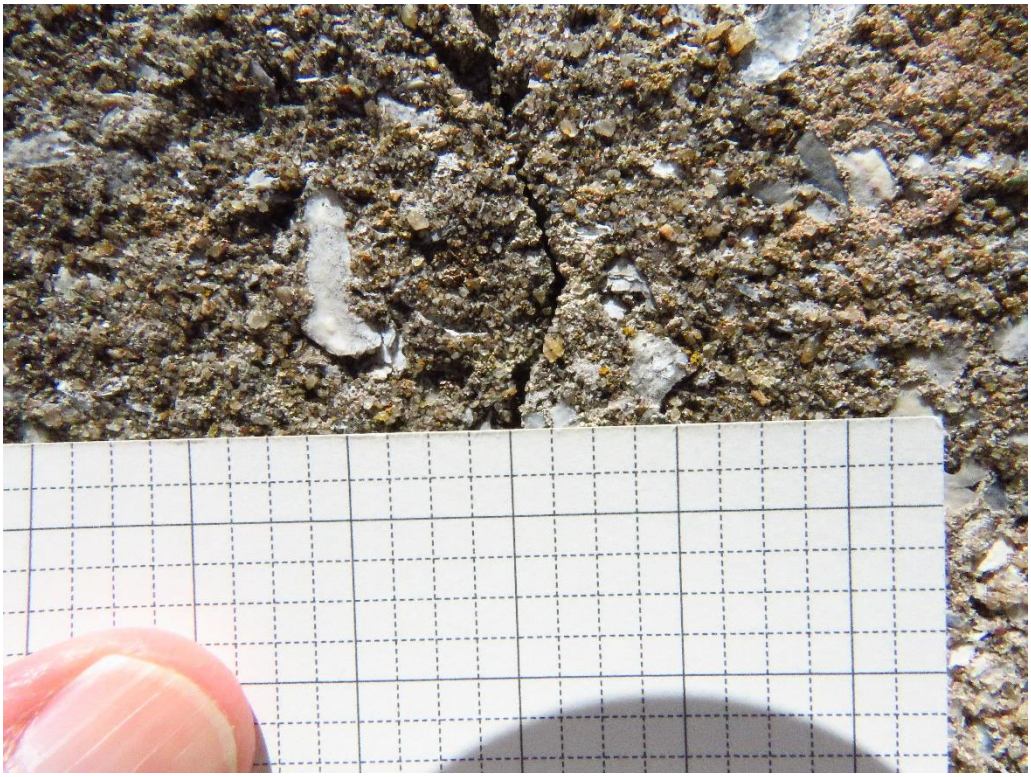


Figure 14: Fine cracking in the west retaining wall along the main north-south pathway.



Figure 15: Cement slurry parging on the south tabby walls of the east entry into the Western Magazine Complex.



Figure 16: Cement slurry parging on the south tabby walls of the east entry into the Western Magazine Complex.