Structures North
60 Washington St, Suite 401
Salem, Massachusetts 01970 3517
PO Box 01971-8560
T 978 745.6817 F 978.745.6067
www.structures-north.com

16 December 2010

US Department of Interior/ National Park Service
Fort Sumter National Monument
1214 Middle Street
Sullivan's Island, SC 29482

Attention: Rick Dorrance, Chief of Resource Management

Reference: Fort Sumter Masonry Conditions

Dear Rick:

On the 15th and 16th of October, 2010, John Wathne visited Fort Sumter National Monument to perform a general observation of the Fort to identify masonry conditions that may be of concern, and to provide a basis for future testing and research going forward. Due to the numerous studies and writings on this national icon Fortress, we will forego the usual historical introduction and type of construction, deferring to the large volume of public domain knowledge on these subjects. We will, however, provide description as it pertains specifically to the issues or conditions at hand.

We have also reviewed reports that were submitted by 4SE Engineers (dated 8 July 2009) and Prof. Denis Brosnan of Clemson University (dated 11 January 2010). The 4SE report was primarily a summary of Structural Engineering concerns regarding the Fort and a series of recommendations for further investigation and interventions. Additionally, Prof. Brosnan's report was a mineralogical study of the Fort's masonry components and includes recommendations for treatment based upon chemical properties without addressing physical requirements. We have attempted to blend the realms of both reports and provide recommendations for masonry restoration materials based upon the physical and performance requirements set forth in the ASTM C1713 standard specification.

The material or elemental conditions in historic structures are often determined by the ability of the materials or components to resist a set of loads, whether they are

structural, environmental, or even functional (such as "the doorway was demolished because it was too narrow"). Materials or elements that are in good condition have successfully sustained these loads while those that are not in good condition have been adversely affected by them.

We will look at materials and structural elements in Fort Sumter in terms of the loads that they are subjected to, and the ways that they have reacted to these loads, followed by a discussion of how successful these have performed and what steps might be taken to relieve some of these loads or improvements that could be made to better resist them.

Loads:

Environmental Loads

Rainwater Soaking and Humidity-

The Fortress is entirely open to the weather and subjected to repeated severe rain storms and fluctuating humidity.

Salt Saturation-

The brick and stone masonry underpinnings of Fort Sumter are literally sitting in a constant bath of salt water, while the majority of the structure remains open to the air. The generally absorbent nature of its brick construction is such that there is a natural tendency for the salt laden water to be absorbed at the structures base and travel upward via capillary action (like a wick), and then be evaporated out of the structure at a height where the capillary action can no longer draw enough water to sustain this outward flow.

Another source of salt infiltration to the structure is salt laden air and sea spray, the severity of which is increased during storms. Rather than an upward wicking action,

this would result in an in-and-out absorption and evaporation over the impacted surfaces.

Salt saturation in general should not be detrimental to the condition of the masonry so long as it remains in liquid state. However, as the evaporation occurs, the salts cryptoflouresce within the outer "evaporation zones" of the masonry.

Salt crystals form and expand within the internal brick matrices in-sighting failure of the internal structures of the bricks and/or mortar as there is no volumetric capacity for the crystals to grow.

Other Chemical Loads-

According the Prof. Brosnan's report, corrosion of the existing mortar by waterborne impurities is another possible mode of damage to the existing masonry and is covered quite well in his report. In addition to this being driven by rising dampness, there has also been concern that rainwater driven chemical effluents from the retained soil mass within the east portion of the Fort may be harming the masonry.

Temperature Fluctuation-

Fort Sumter is subtropical climate and is very exposed to the air. One would anticipate a relatively high degree of fluctuation between seasonally and even daily high and low temperatures.

Wave Action and Wind -

The salient, flanking and right face walls are subject to wave action, as an effect of severe weather and the tidal cycles. In addition, under certain conditions the south side of the gorge wall might also be impacted by waves.

Beyond the direct scouring of waves, another effect is the shifting of rip rap stones that grind against the brick surfaces of the Fort causing them to abrade.

Wind is another loading consideration that under normal conditions would not adversely affect the

Fort. However, it would tend to drive sand and other airborne particles that can abrade the exposed surfaces, as will rain and seawater during storms while accelerating evaporation (and saltwater uptake) during dry periods.

Structural Loads

Material Dead Loads-

The weight of the structure itself is carried by the structural elements that support it- some of these being the walls, the piers, lintels, arches and foundations. Some of these loads have been reduced or even eliminated over much of the original Fortress due to the loss of the upper gallery and the elimination of casemates and other structures. While this reduction in load has provided a relief to foundations, there has also been a redistribution of forces due to the loss of their countering effects, as will be discussed later in this report.

Gravity Live Loads-

The Fort presently serves as a public "museum" space, sustaining theoretical live loads of up to 100 pounds per square foot on any horizontal surface at any time. Except where countering forces on specific elements have been eliminated (as noted above), such live loads should not be a concern or consideration given the tremendous blast and impact loading for which the fortress was constructed to resist.

Soil Loads-

The infilling of the eastern portion of the Fort with soil has placed unbalanced soil pressures against the wall and casemate structures which must laterally retain this soil. It has also increased the gravity load on the soil that underlies the foundations.

Wind and/or Seismic Loads-

Even with its very exposed, hurricane prone location, Fort Sumter, being of massive, heavy masonry construction, should not be prone to significant damage from wind forces, or even the forces of wind-driven waves.

Being within a seismically active region (Zone 2) of the United States, there is the possibility that a damaging earthquake could occur. The massiveness and heavy weight of the fort's construction makes it especially prone to high loads resulting from vibratory ground movements, however, the robustness of its construction

makes it more resistant. *An evaluation of seismic resistance and risk is beyond the scope of this report but is recommended.*

Blast and Impact Loads-

With its pivotal role in the American Civil War, Fort Sumter was subjected to tremendous impact and blast loads during its bombardment. Much of the original fabric of the fortress was unfortunately lost and required reconstruction as a result.

Materials:

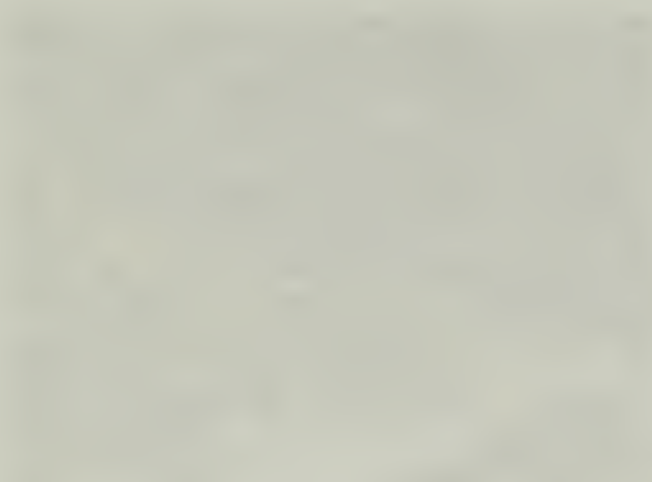
Fort Sumter is primarily constructed with for types of materials:

1. Red Common Brick: This comprises the majority of Fort Sumter's early to mid 19th Century construction and has been researched and well described by Prof. Brosnan and consists of four "families" of bricks that were hand molded from coastal clays and one "family" of extruded bricks. The bricks are generally weaker and more porous than bricks that would be used in such applications today. Such bricks could be, and in many cases have been, damaged by improper selection of mortar, which would need to be very breathable and relatively soft to behave compatibly with the brick.

2. Red Sand Stone (Red Stone): This is a local sedimentary stone that has been used at the interior faces of the embrasures.

3. Granitic Stones: Granite and other hard igneous rocks have been used to construct a rip rap that runs around the east side of the Fort, as well as in front of gun emplacements. This is the hardest material in the fortress and not necessarily mechanically compatible with other materials that it is in contact.

[illegible]



[illegible]

4. Cement, Lime and Sand Based Mortar: According to Prof. Brosnan's analysis, the mortar that was used to lay the brick and stonework contained natural cement and sand, along with suspected traces of lime.

5. Tabby: Lime-based concrete made with oyster shell aggregate. This was typically used as infill (possibly as a shock absorber) within brick masonry construction and at the exterior faces of embrasures under a protective layer of stucco.

6. Stone Concrete: Cement based concrete with small stone aggregate.

Noted Material and Structural Conditions:

During my 1½ days on site, we made a full visual inspection of all of the 19-century fort elements, making a few limited test probes into the construction. Because there was insufficient time to conduct a full mapping of each and every condition, we made a general mapping and inventory of the types of conditions encountered. Rather than presenting the entire litany of conditions and their locations, which is beyond the scope of this report, we provide the following description of each type of condition encountered, grouped categorically by the issues within the Fortress that relate to them:

Material Conditions-

Peeling and Spalling of Brick Surfaces-

We found many zones in the exposed wall construction where bricks have been surface-spalling in successive layers, often with entire partial-wythe sheets of brick which remain bonded together peeling off of the walls.

In these zones the mortar and the bricks appear to be of the same relative permeability and strength. Consequently, there does not seem to be one acting sacrificially for the other, rather they both seem to compete equally and both fail at the same time.

The actual mechanics driving these surface failures involve cryptoflorescence as described earlier in this

report. Where the mortar between bricks is relatively sound and the bricks relatively impervious, the zone of evaporation reaches only a few inches inward from the surface, thus the thicknesses of the sheets are limited.

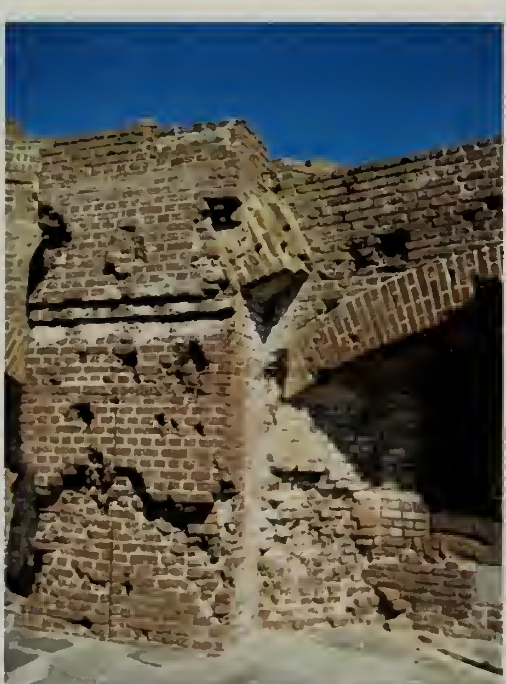
Three variants of this condition were encountered:

- True-surfaced hollow sounding areas: These are places where delamination has occurred but not to the point that the affected brickwork had spalled. When tapped these have a tighter sounding ring than separated wythes due to the good adhesion of the bricks and mortar within the peeling planes.

- Rough surfaced solid sounding areas: These are places where the outer surface of brick has already spalled but the next successive spall line has not yet formed.

- Rough surfaced hollow sounding areas: These are places that have already surface spalled and the next sheet of spall has already formed.

Separation and Delamination of Brick Wythes-



We also found areas, particularly at the Parade side of the scarp walls where the wythes of brickwork seemed to be separating from each other while the actual brick units remain intact. The mortar between at least the first and second brick wythe and in some cases the second and third, have lost all binder and remain as uncemented damp sand. Tapping with a hammer can actually push the outer bricks slowly inward as the unbound collar joints compress.

This condition typically occurred where the mortar seemed softer than the bricks, effectively causing saturation and deterioration at the surface, while cryptoforescing salts caused damaged deeper within the walls.

We saw two variants of this condition:

- Brick surfaces with exposed softened mortar joints, sometimes deeply eroded.

- Brick surfaces with hard mortar repointing over soft, decomposed mortar behind it- typically very damp due to the entrapment of moisture behind the harder mortar. In most cases the hard mortar joints are cracked.

Individually Eroding or Spalling Bricks Surrounded by Raised Ridges of Mortar-

These are areas where the brick is softer and more breathable than the mortar. Vapor transfer and cryptoflorescence is occurring through the bricks, which are sacrificing themselves to the mortar. A clear indication of this is where the header bricks, which run deeper into the wall construction than the stretchers, fail the most. This is due to the bricks acting as wicks, drying out the interiors of the walls.

Eroded Red Stone-

Several of the red stone units are eroded and have bedding plane delaminations, as would be expected for this relatively soft material in a harsh environment.

Cracked, Spalled Granite-

Several of the granite units are cracked and spalled at gun emplacements, possibly due to heat or impact damage.

Eroded, Cracked Tabby-

Exposed tabby has for the most part performed extremely well, with the exception of a few locations where it has eroded, pitted, and/or cracked and spalled.

<u>*Mechanical Conditions*</u>

Blast Damage-

We saw several locations where there were cracks and divots that could not be explained other than by the presence of impacted ordnance or missing shells that had rebounded or been removed. One must be reminded that the present structure

[illegible]

[illegible]

has less than a third of its original as-built fabric still remaining due to the tremendous bombardment that it sustained at the opening of the Civil War.

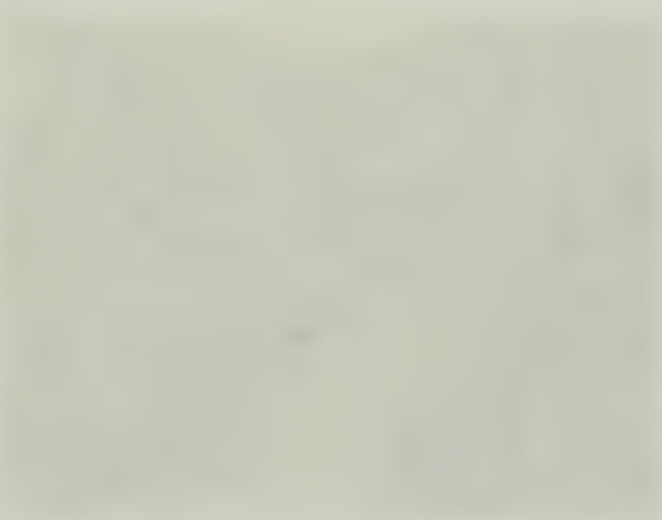
Major portions of the original construction are missing as a result of this bombardment, and other elements remain damaged, having not been reconstructed as part of the 1870's repairs.

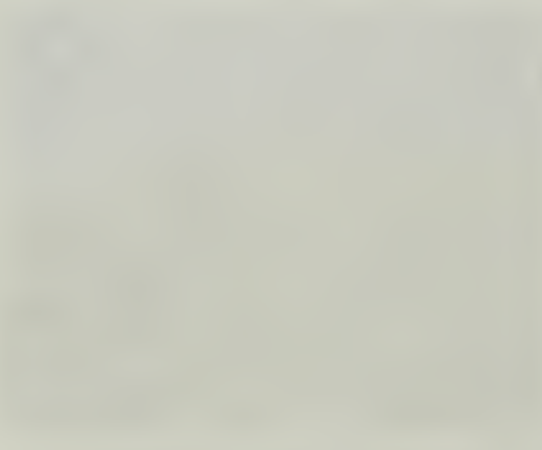
Riprap Abrasion-

Many of the stones that form the breakwater are leaning against the perimeter walls in a somewhat unstable fashion and obviously move around when impacted by waves. This causes the contact points to abrade the wall surfaces and over time, grind depressions or divots into it, in some cases, as much as 6 to 8 inches deep. Proof of how much some of these stones actually moved was exemplified by our discovery of a late model tire that had been wedged beneath one of the larger stones.

Differential Thermal Movement and Moisture Growth-

The combined effects of thermal strain and moisture growth result in lengthening of long stretches of brick masonry, particularly the upper portions of the Fort where the brickwork heats up and expands more, is subject to more frequent wettings, and is in many places of a later construction than what is beneath. This means that the upper masonry elongates more than the lower masonry with a ratcheting effect causing cracks and the upper portions of corners to bend outward. Although moisture growth takes place shortly after the brickwork is installed, the debonding and cracking that often results allows less constrained movement under temperature fluctuations that continue to occur





throughout the structure's life, thus increasing the total amount of movement and damage.

Elemental Hazards-

There are places where material failures have resulted in loose or unstable elements that are too small to be considered structures. Such cases involve loose bricks or spalls and a large chunk of a brick pier near the northeast corner of the Fort that could fall.

Structural Conditions

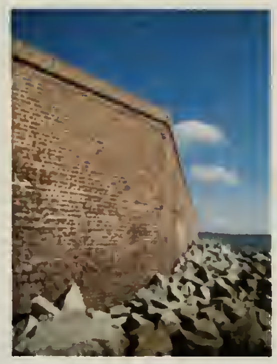
There are several conditions that in my opinion are direct results of imposed structural loads, whether live loads, dead loads or soil loads.

Spreading Arches-

There are vertical cracks running through the center of many of the transverse arches that support the casemate vaults. While in the typical spans these are small, they are considerably larger in the radially oriented arches that fan the corners of the Fort and have longer spans. This is probably due in part to the fact that these are longer spans, with higher total span loads, and in part to the fact that these occur at corners where there is less direct horizontal restraint.

Outward Moving Corners of Walls-

Coupled with the wider cracks in the radially oriented arches are diagonal shear type cracks in the supporting piers and walls, and noticeable outward sweeping and leaning of the perimeter walls at corners.



The unrestrained spreading forces at the ends of the long arches (please see "Spreading Arches", above) has caused the corners of the Fortress to lean outward. The actual leaning has been allowed by forced foundation settlement, as the resulting stress distributions on the bottoms of the footings would be unbalanced, and by cracking in the walls and longitudinal corner movements noted below.

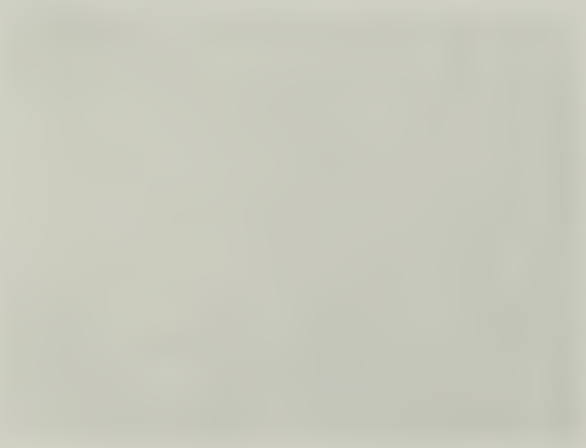
Brick moisture growth, and to a lesser extent ratcheting thermal expansion, has resulted in a net Lengthening of the walls (please see "Differential Thermal Movement and Moisture Growth", above). This has caused the ends of the walls to crack and to bend outward at each corner, as they have nowhere else to go, combining in effect with leaning and spreading of arches.

Cracked and Spalled Piers-

As a response to the "negative" bending rotation at the ends of the spreading arches and the outward movements of the supports, vertical and diagonal cracks have formed in supporting piers and the ends of arch spans which have been forced to change shape as a result of the movements. At some locations concentrations of compression stress at the hinge points of the arches have caused the brick masonry to spall.

Shear-Cracked Vaults-

There are also transverse and diagonal cracks in many of the vaults that are likely the result of the arch spreading and wall-lengthening movements described above. As rigid, horizontal shear resisting diaphragm elements, the vaults have attempted to resist the longitudinal and outward corner



movements of the walls (please see "Outward Moving Corners of Walls", above), however their in-plane shear capacities (diaphragm resistance) have been exceeded, resulting in cracks.

Another cause of such cracking, at least locally, is the loss of restraint caused by the removal of multiple arches and the north wall of the parade.

Repetitively Cracked Walls-

As a result of unbalanced moisture growth and thermal strains, horizontal cracks have formed between different behaving portions of walls, often resulting in diagonal cracks at the ends and/or vertical cracks along their lengths.

The most obvious location where this has occurred is at the right flank wall where there is a large diagonal crack and a planar shift at the east end. This was caused by the expansion of the newer brick cap that was added atop the wall, dragging the corner along by its outward movement.

In other places there are repetitive vertical cracks in the walls that most likely relate to repeated heating and cooling of the long, continuous brick surfaces which, according to tests that were performed by Prof. Brosnan, are unusually prone to thermal expansion and contraction.

Conclusions and Recommendations:

In consideration of the preceding information, one can draw some general conclusions regarding the on-going issues that face the Fortress, and can begin to make some recommendations:

Material Performance and Durability Concerns-

It appears that the fortress is under a considerable environmental load, especially when one considers the combined effects of constant salt saturation, thermal cycling, and wetting and drying. Given all of this and the fact that the apparent depth

of damage is limited from 4" to 8" on each face of 6-foot thick walls, we believe that as a whole, the brick and mortar materials are performing quite well. So far it appears that the limited depth of damage makes the walls unsightly and threatens the risk of individual falling bricks, however the basic mass of the structure has been well preserved.

Internal Wall Conditions

The lower portions of the interiors of the thick masonry walls are saturated with salt laden water at all times. Where this remains in a liquid state, this should theoretically cause no damage to the masonry. The damage, as we can see, occurs where the salt laden water evaporates. Assuming there is a maximum height to which capillarity can pull the water and that the top of the walls are mostly dry, then it stands to reason that there should be a horizontal evaporation frontier within the walls, in addition to the vertical planes on the walls sides.

We believe the reason we don't see a salt-jacked horizontal crack-plane running through the wall like the vertical delamination planes is two-fold: (1) the water vapor must travel a much farther distance upward to reach the atmosphere than to the side, so it goes out the sides, and (2) there is sufficient overburden on the wall construction so that it doesn't lift.

To verify these assumptions, we suggest the drilling of several cores through the wall construction in order to confirm the sound conditions of the wall construction inside. The absence of macroscopic bursting cracks throughout the masonry means that the cored brickwork will probably be very sound.

Drying and monitoring the salt water-saturated cores might also be helpful in confirming that the possible one-time drying out of the walls by capping or removing the earthen fill will not damage the walls (please see *Structural Performance Concerns/ Surcharging Earthen Fill*).

All core holes should be plugged or at least made watertight so that they do not become outlets for salt exfoliation.

Restoration/ Repair Material Selection-

The present concern, however, is how to properly select masonry restoration materials to be used in the Fortress, and how to verify that the conditions within the

interiors of the massive masonry elements are, in fact, in as good of condition as they seem likely to be.

There have been numerous restoration campaigns attempted on the Fortress. Some of these included reconstruction, while others just maintenance such as repointing of mortar joints. Some of which appear to have been effective, and some appear to have not.

Beyond the somewhat difficult aesthetic and durability challenges to be faced in selecting the proper brick, the most difficult challenge is selecting the proper and most compatible restoration mortar. This is because, in my opinion, the original mortar is in some ways a moving target.

According to analyses by Prof. Brosnan, the original bedding and pointing mortar used in the Fortress consisted of natural cement and sand, with the possibility of limited amounts of lime. Such mortars were commonly used in the early to mid 19^{th} century for larger well-funded structures, especially fortifications. Being fired and ground from stones taken directly out of the ground, properties of natural cement were always dependent upon the qualities and consistencies of the mined stones. Having researched the engineering properties of natural cements from historical texts in preparation for the First Natural Cement Conference in 2005, we found that the engineering properties varied widely between different brands that presumably came from different deposits, even when evaluated under the same testing programs. Because of the sheer size of Fort Sumter, its remoteness, and the fact that it was constructed over the course of several years, it is likely that the cements used were from several locations, if even just in different strata from within the same "cement rock" vein.

This would explain some of the variability in performance and perceived hardness that has been noted within different parts of the Fort which had theoretically been constructed using the same materials.

In selection of repair materials, the most obvious formulations would be combinations of natural cement and sand, or Portland cement and sand down-gaged with lime in order to decrease strength and hardness. Fort Sumter has served as a wonderful testing laboratory for restoration materials as several have been used. Mortars with too high a lime content have eroded away, while mortars with too high a Portland cement content have entrapped moisture and caused failure to occur within the substrate it was intended to protect. Most of the repairs using natural cement appear to have performed well, however, these may be too recent to have a

sufficient performance history and Prof. Brosnan has expressed concern over mineralogical consistency in the purchased products.

According to your office, three possible mortar formulations are presently being considered for the restoration and repairs at Fort Sumter.

From a very basic standpoint, it would appear that restoring the fortress using natural cement and sand mortar would be the most materially and historically appropriate solution. We understand your concerns over consistency of the purchased product, which from my historical research has been an inherent problem with natural cement from the time it was first produced. Therefore we are actually faced with two moving targets, one being potential variability in the as-purchased material and the other being variability in the in-situ material.

With the recent publishing of ASTM C1713, the Standard Specification for the Repair of Historic Masonry, for which I am the developmental Task Group chair, we now have a guide for the selection of restoration mortars based upon engineering and performance properties. Part of the intent of this specification is that in-situ materials can be evaluated using the same tests that are specified for the restoration materials so that direct comparisons can be made between them and a scientific basis can be established for their selection.

The following tests should be conducted on the existing in-situ materials:

- E-96 (modified) water vapor permeability (WVP) for each known brick type and at least 10 mortar samples of different appearing behavior. This is an extremely important property when considering the selection of restoration mortars that will basically encapsulate the original masonry mass.

- ASTM C109 compressive strength test, if possible, on at least five samples of each known brick "family" and mortar type. Mortar tests will have to be corrected for the small sizes of sample, and a procedure would need to be developed for stack-bonding saw cut mortar joint samples with as thin a grout layer as possible of similarly formulated material (multiple 3/8" mortar joints samples stacked with 1/32" to 1/16" leveling grout would still contain 83% to 92% joint mortar and would provide a good approximation of in-situ mortar strength).

- In historic masonry restoration, maximum compressive strength is often at least as important as minimum compressive strength. Not only is compressive strength a proportional indicator of other properties such as elastic modulus and

tensile strength, too weak a mortar can fail prematurely while too strong a mortar can fail the substrate.

- ASTM C1357 (modified) flexural bond strength tests on at least five brick and mortar assemblies. The bond strength between the mortar and the masonry units is extremely important in historic masonry structures because of the frequent tensile stresses that develop in the masonry mass during heating and cooling cycles. Sample sizes should be 3 5/8" wide (1-wythe) by 7 5/8" long (one brick length) by 15 5/8" high (six courses).

The test results should be evaluated in order to establish target ranges for the desired properties. Target properties for the new mortar should be as follow:

- Compressive strength should be mid-range between the high and low tested strengths of the in-situ mortar, but in all cases at least 50% lower than the lowest average compressive strength of the brick.

- Water vapor permeability should be the same or greater than the WVP of the existing mortar and at least 50% higher than the average of the most breathable brick.

- Flexural bond strength should be mid-range between the highest and lowest using thoroughly cleaned samples of the original in-situ bricks.

New trial mortar formulations should be developed and tested in accordance with C1713 that meet the above criteria. If this is done, then as long as there is no chemical incompatibility between the existing and new mortar (which there should not be if like kind materials are used) then the new materials should perform at least as well as the original ones, which in my opinion was very well.

Recent research by Columbia University that was recently presented at the APTI conference in Denver compared various mortar binder materials and found that the natural cement mortar formulations had exceptionally high water vapor transmission properties when compared to down-gaged Portland cement mortars in a similar strength range. The WVP was on a par with hydraulic lime, which is considerably weaker and often less durable. This may explain why so many monumental structures built with natural cement have performed so well. We have great confidence that a proper natural cement and sand formulation, perhaps with the addition of small amounts of lime, will yield results that fall into the desired ranges.

Natural cement is now available domestically from two producers: Edison Coatings of Plainville, CT; and Freedom Cement of North Brookfield, MA. Both Edison's "Rosendale Cement" and a pre-cursor to "Freedom" were used in the restoration of Fort Jefferson in the Dry Tortugas.

Eroded Stone Units and Concrete-

Stone units and exposed, unreinforced stones that have eroded or cracked in such a way as it poses no threat of instability may be left in their present state. They are just undergoing a natural aging process and it would be difficult and costly, as well as unnecessary, to create long lasting patches that do not stand out visually.

Structural Performance and Abrasion Concerns

Structurally Cracked or Damaged Elements-

All of the cracks, shifts and planar irregularities at Fort Sumter can be attributed to the combination of structural and, in some cases, environmental loads that affect these responses. While the resulting damage can simply be repaired (please see below), the question remains as to whether these conditions will reoccur or whether the affected elements are sufficiently safe.

Structural Stability and Safety-

It would logically be assumed that the age, severe history and the fact that the structure is still standing after enduring events of the past speaks to its safety and to the mastery of its original builders. It must be recalled, however, that what remains is simply part of a once larger fort, and that the vertical loads on the restraining walls and piers are considerably less, at present, than when they were originally designed. Could some of the movements be the result of loss of restraining force?

And, even if Fort Sumter is safe today, would this national icon survive a potentially damaging earthquake?

The best way of answering these questions is through structural analysis. There are two levels of analysis that can be used- planar and three-dimensional. The first is a reasonable approximation of reality and the second is a closer one.

Planar analysis basically involves the creation of representative 2-dimensional models that approximate the two-dimensional behavior of 3-dimensional elements.

In most cases these approximations are fine. The results of multiple 2-dimensional analysis can be summed to approximate three dimensions and can yield a pretty good understanding of the structure, subject to the intuitiveness of the summed model's creator.

3-dimensional analysis is a bit more complex and involves the use of a computer (typically "finite elements") program to analyze a complex 3-dimensional computer model of the structure. This is much more expensive and involved, and carries a somewhat higher risk as the results are only as accurate as the data that is entered into the program by a human being with no intuitive sense of how the model's results are actually calculated.

Because 2-D analysis is much less expensive than 3-D, we recommend that 2-D be used to analyzed all of arches, vaults, piers and important walls, along with any structural elements that have cracked. If the perceived level of safety that results from such analysis is not at least 10 percent above "adequate" or 50 percent below, then the results would be considered inconclusive and a 3-dimensional analysis should be attempted. The definition of "adequate" would mean "safe" according to code.

Assuming the structure is deemed adequate under the above criteria, the structure can be routinely and material-appropriately repaired.

If certain portions of the structure do not pass, then hidden reinforcement or externally applied bolstering measures should be implemented but only where deemed necessary as these will affect the historical integrity of the Fort. Deficiencies that immediately affect live safety should be given the highest priority.

Adequacy of Foundations-

There has been some level of concern over the stability and adequacy of the Fort's foundations. During my evaluation, we observed the lowest visible portions of the foundations and found them to be in very good condition.

According to historical surveying data, it is thought that the fort has settled by as much as several feet since its original construction. Other than for the tilting of corners, we found no sign of any significant damage that we would have attributed to ground movements, and given the overall lightening of the structure (with the exception of the earthen fill at the east portion of the site), there should be no more downward movement anticipated. We do not therefore believe that the expense or

effort of an on-going level monitoring program can be justified, unless to establish a baseline for future level monitoring should any significant bearing pressure changes be affected such as by backfill removal or rip-rap reconfiguration.

Surcharging Earthen Fill-

There is also concern over the fill that has been added to the eastern portion of the site and its structural and chemical effects. During my observation we did not see any obvious signs of outward movement or damage that would have resulted from the presence of fill against the inner walls and arches of the Fort. This either means that the fill was placed in a careful or retained manner that would not destabilize the perimeter walls, or the individuals placing the fill simply got lucky because the Fort was sufficiently robust to resist the additional lateral load.

Reasons in favor of removing the fill would be if the lateral earth pressure were causing damage, which we do not see any sign of (the fill on the high side of the wall was apparently placed 70-years before the riprap, therefore it is likely that the riprap is not critical in buttressing the wall. Another reason would be if the fill is causing internal damage to the wall- which can only be determined by core-drilling or test pits.

Reasons supporting the removal of the fill include the fact that the soil removal might result in an upward rebound of the supporting subgrade that could crack the wall, and more practically, the fact that there is no known record of the condition that the buried portions of the Fort. Such exposure would only compound the maintenance and repair burden of the Fort.

One way around the possible chemical concerns would be to cap the fill with a buried membrane and under-drain system that would prevent any rainwater or salt spray from percolating into (and through and then out of) the fill by collecting and channeling it away.

Abrading Walls-

In order to best stop the on-going stone abrasion of the walls the riprap against them should either be moved away from the walls, or protected with new rip-rap that is located further away from the Fort.

Details of Repairs

Repairs should be made in as sympathetic a way as possible, and per the Secretary of Interior's Standards, and in such a way as they can be reversed, however, the actual practicality of this in some cases may be questionable.

Repointing/ Rebuilding-

Sections or portions of walls that are badly joint eroded or spalled should be cut and repointed and where needed, reconstructed. Loose and/or unstable elements should be removed and either reattached, or replicated or rebuilt.

Repointing should involve cutting of joints to a minimum depth of 2 ½-times their exterior widths, and should include materials that, in addition to the aforementioned compatibility concerns, should be visually indistinct.

Wherever possible reconstruction should utilize harvested matching brick, or at least not less than a 50% mix of harvested and new replacement brick in order to limit differential moisture growth between existing and replacement elements. Another alternative is pre-acclimating or seasoning the new brick for at least 12-months under weather and exposure conditions that match or exceed in severity the anticipated conditions in service. Large scale brick replacements with unseasoned new brick which is restrained by surrounding old brick construction simply will not work.

Bond, geometry and configuration should match the original.

Structural Crack Repair-

Structural cracks should be excavated to a depth of at least two wythes, cleaned, flushed out, and then injected with a fluidified version of a compatible mortar (or grout). The excavations should then be stitched back together with as many as possible of the same, original brick.

It is has been both a pleasure and an honor to consult to you on this historically iconic structure. Please contact us if you have any questions or if we can be of further assistance.

Respectfully yours,

STRUCTURES NORTH CONSULTING ENGINEERS, INC.

John M. Wathne, PE (MA), President

Ryan Lezak, PE (SC)