

COMPOSITE ANCHORING, GROUTING AND STABILIZATION OF THE BRISTOL MARITIME ARMORY

BY JOHN M. WATHNE

BACKGROUND

The Bristol Maritime Armory, on a wharf in Bristol, Rhode Island, is an imposing two and one-half story turreted granite edifice that appears to stand guard on the Bristol Harbor (Fig. 1). Behind its imposing façade; however, it is a poorly-constructed stack of unbonded stonework. Nineteenth century newspaper articles state that the Armory walls were cracking and bulging even in the first few years following its construction.



Fig. 1: The Bristol Maritime Armory

Built in 1896, the Bristol Naval Reserve Armory served its original purpose for the better part of a century. In 1968, the armory was acquired by the Town of Bristol and converted to a community center and the Bristol Harbormaster's office.

The existing structure is clad in uncoursed, random ashlar granite, semi-wet-laid against both brick and stone rubble back-up wall construction, and depending upon the location within the structure, brick infills. The front section of the building has two floors, an attic and a flat roof which is bounded by a granite-faced parapet wall. There are turrets at the northeast, southeast and southwest corners and a tower at the northwest corner. Most of the back-up wall construction is composed of semi-wet-laid stone rubble, with at least one limited area of brick back-up at the east wall's first floor in the boiler room.

HISTORICAL DAMAGE AND REPAIRS

Local newspaper references from between the start of construction in 1894 and its completion in 1896 portray a project that got off to a less-than-favorable start. For example, an October 20, 1894 article in the *Bristol Phoenix* stated that there was concern over the budget for the project. It stated that "the plans [would] have to be somewhat modified to suit the amount [of money] appropriated, and it [was at that time] doubtful as to whether the first plans and specifications [would] be adhered to." Earlier in the article, it is stated that "it is possible that they [could make] a decision before the extreme cold weather sets in, in order that the stone work for the foundations [could] be a good portion done before the winter." This suggests that "value engineering" decisions were made and that they had hope that foundation work might proceed through the dead of winter.

Less than a year into the project, cracks started appearing in the exterior, and according to a September 1895 *Bristol Phoenix* article, the constructors had attempted to build the tower portion at the

northwest corner and had to dismantle it before it collapsed. An October 1895 article in the same newspaper stated that “an experienced man from Providence” was hired to attempt to grout and pin portions of the walls together so that the tower portion could be re-erected.

Unfortunately, the cracking problems did not stop with the completion of construction. The July 12, 1907 *Bristol Phoenix* commented that “yesterday the work of repairing the walls [had] begun on the Naval Reserve Armory.” As part of this work, the entire southeast corner was apparently dismantled and reconstructed. The cause of damage was thought to be insufficient lapping or “bucking” of the stonework, which would have provided better continuity. A subsequent article referred to the northeast and southeast corners of the structure having been cracked “for nearly twelve years”.

The Armory apparently suffered from storm damage as well. During the famous hurricane of 1938, a “tidal wave” pounded into it, re-cracking some of the exterior masonry walls. This same storm drove a large boat into the side of the neighboring DeWolf Warehouse, leaving a permanent impression on its south side (this historically significant oddity was carefully retained as part of a 2003 renovation of the building).

INTO THE 21ST CENTURY

2007 Assessment

Following its acquisition by the Town of Bristol, and after several decades of stop-gap measures and maintenance repairs, the Town of Bristol retained an engineer in 2007 to conduct a comprehensive assessment of the structure.

For the exterior front section, the assessment report included the following:

- Large cracks, or at least signs of large cracks, are scattered about the exterior and occur at the following locations:

-Wide vertically oriented mortar patches correspond to cracks occurring in the east half of the north elevation and throughout the east and west elevations. While the mortar remains intact, nearly all of these mortar patches have re-cracked with the same orientations.

-Line of vertically oriented cracks and widened joints occur within the northeast turret, all of which have been patched with mortar and re-cracked.

-Vertical cracks occur above each side of the intersecting rear section, all of which have been mortar patched and nearly all of which have re-cracked.

-Wide, open crack exists along the east edge of the southwest turret, seemingly caused by the outward spreading of the corner and separation of the turret from the south wall.

-Vertically oriented, mortar patched cracks in the west wall of the tower have re-cracked. The crack in the tower wall is at its widest at mid-height.

- A dangerously large bulge exists in the north half of the east wall at about mid height. By creating a hole in the window surround within the bulged area, it was apparent that the bulge was actually a separation between the exterior stone leaf and the random stone back-up construction.

It was obvious that what had been an early history of exterior cracking had continued to progress.

2008 Repairs

The first phase of repairs focused on the severely-cracked northeast turret and the cracked and bulging east elevation (Fig 2 and 3). Initially, the repairs were intended to consist of through-pinning the elevation and gravity-filling and packing the back-up construction with mortar and chinking stones by opening small windows at removed stone. However, the conditions encountered during construction were so severe it was determined that it would be necessary to do a comprehensive reconstruction of the middle portion of the façade and a total reconstruction of the turret.



Fig. 2: Internal turret condition



Fig. 3: Internal wall condition

This work was done using ASTM C270¹-style Portland cement, hydrated lime and sand blends, both in standard mortar consistency and (with the addition of a shrinkage compensator) in the form of a fluid grout.

While this work did successfully put the stonework back together, it did so with significant disruption and at significant cost. Moreover, with the large volume of mortar that this work required in a tightly enclosed environment, the hydrated lime component in the mortar did not fully cure before white streaks became visible on the exterior. Lime cures through exposure to carbon dioxide in the atmosphere, and if contained in a large volume and sealed on all sides, such as in a thick wall or turret, there is not enough atmospheric interaction for cure to happen. The unsightly white streaks were thus considered to be an unavoidable result of the available construction technology at the time.

DEVELOPMENT OF A NEW ANCHOR SYSTEM

During the years after the completion of the 2008 Repair Program, a new composite grouting and lateral tying system was researched and developed that would be able to stabilize the structure in place.

To create the best combination of grout injection and lateral restraint, the grout should be injected at the same location as the anchor. However, because the anchors had to already be in place to resist the pressures of the grouting, the anchor itself was designed to inject the grout.

Port Anchor and Cavity-Filling Grout Development

Working with an anchor system manufacturer, many different anchor prototypes were analyzed and tested before arriving at some practical, standardized designs (Fig. 4 and 5).

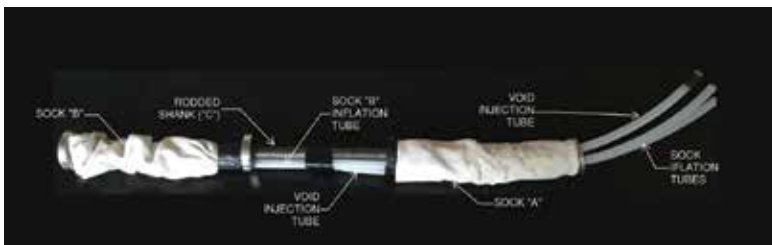


Fig. 4: Rodded shank anchor

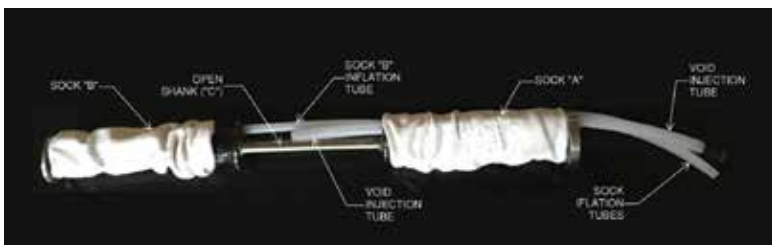


Fig. 5: Open shank anchor

After the port anchors were developed, however, a materially-compatible grout had to be developed to put through them. The design requirements of this material would be as follows:

Moderate strength: Because of the low-to-moderate strength of the substrate materials, too strong a grout would be physically incompatible and would act like a knife blade within the masonry matrix of the wall.

Breathability: The grout would need to have a water vapor permeability that is not significantly different than the combination of historic parent materials, in order to avoid creating a vapor lock within the structure where moisture could condense and promote deterioration of the masonry.

Freeze-thaw durability: The grout would need to go through numerous freezing and thawing cycles without sustaining material damage.

Flowability: The grout would need to be flowable enough to get through the injection apparatus and flow into the voids.

Low shrinkage: The injected grout cannot shrink significantly or any bond that is established between the leaves would be lost. Alternatively, expansion could not be permitted because of the potentially destabilizing jacking forces that this could put into the structure.

High Adhesive Strength: It is important that the grout be adhesive enough to bond surfaces together with an adhesive strength that equals or exceeds the cohesive strength of the grout (Fig. 6). This is so that any shrinkage that did occur would result in jagged microcracks within the grout rather than in debonding from the substrate surfaces.



Fig. 6: Bond test specimens

Non-corrosion: Certain additives, such as shrinkage compensators, can promote the corrosion of metal with which they come in contact.

Hydraulic Hardening: Ability to cure in an anaerobic environment is extremely important, particularly as the reaction of all materials can prevent the leaching of lime and its appearance on the surface.

After experimenting unsuccessfully with several off-the-shelf non-shrink grouts and modifications

of them, the best results were achieved with a pozzolanic hydraulic lime (PHL) binder mix. After much experimentation, a finely sanded pozzolan-lime grout with a small amount of Portland cement was created that met all of the above requirements, with the binder meeting the more specific requirements of ASTM C1707² as a pozzolanic hydraulic lime “PHLc” with a maximum 20% binder weight of hydraulic cement (PHLc).

Extensive testing was then done on the mix to qualify under ASTM C1713³ as a fluid replacement for a specific range of historic mortars.

Resisting grouting pressures: The introduction of a contained fluid into a masonry structure exerts bursting pressures roughly equal to the total fluid weight of the material. The port anchor design resists these pressures as a pre-installed tie.

Providing general confinement to the masonry mass and resisting external or internal splitting forces: The confinement provided by the anchors can counter thermal and moisture stresses that might tend to debond the leaves, counter buckling and splitting forces that might result from high compression loads, or counter tension forces from corbels and cantilevers.

Resisting flexural “rolling” shear: The confinement provided by the port anchors helps maintain the grout adhesion between leaves, resisting in-plane shear forces between them so that the masonry can act as one single mass.

COMPOSITE WALL REPAIRS IN 2015/2016 PROGRAM

In 2015, the Town of Bristol embarked on a significant rehabilitation project at the

Armory. The composite anchoring and grouting system was selected as the system that would rehabilitate the masonry structure.

The first step was to perform an updated survey of the structure to lay out the anchor locations. Anchors were positioned where they could be of the greatest value, such as along cracks, at the centers of bulges, and at protruding large stones (Fig. 8). Holes were core-drilled through the wall and the outer leaf, and back-up thicknesses were determined. Interestingly, between 10 and 20 per-

Tested Properties of the PHLc Grout used on Bristol Project

Cement content by weight of binder:	< 15% meeting ASTM C1707 ² as a “PHLc”
Chloride content by total cured weight:	0.002%
Flowability:	135% per ASTM C230 ⁴
Dimension change after hardening:	0.06% per ASTM C1090 ⁵
Standard curing time (CT):	120 days per ASTM C1713 ³
Water vapor transmission:	1.9 g water/ sq meter/ hour per ASTM E96 ⁶ (modified)
Mean compressive strength:	>80 psi at 2 days (limited by Poisson’s strain, not fracture) 1414 psi at 28 days, SD= 214 psi (fracture) 1734 psi at 90 days, SD= 226 psi (fracture) 1877 psi at 120 days, SD= 185 psi (fracture)
Mean tensile bond strength:	48 psi at 28 days per ASTM C952 ⁷ (brick)

A full paper concerning the grout and its development was presented in 2013 at the 3rd Historic Mortars Conference in Glasgow, Scotland⁸.

STRUCTURAL FUNCTION OF THE PORT ANCHOR COMPOSITE MASONRY SYSTEM

The structural performance of the tie and grouting system (Fig. 7) has several components:

Lateral tying capability: The initial installation of the anchors is intended to provide a lateral tension tie between separated masonry leaves.

Providing a port or pathway into the masonry core for grouting: The port anchor provides the path for grout to be introduced into the masonry mass at the point where the cavity can most easily be cleaned and where the bond is most critical.



Fig. 7: The composite masonry system (illustrated)

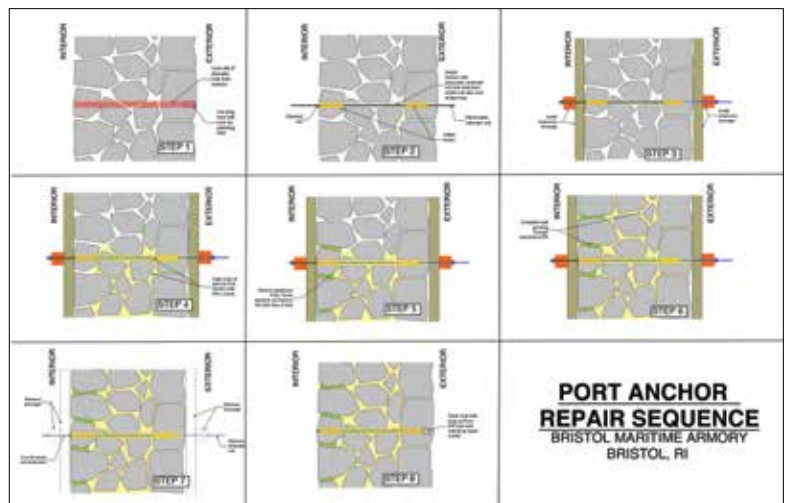


Fig. 8: Port anchor repair sequence

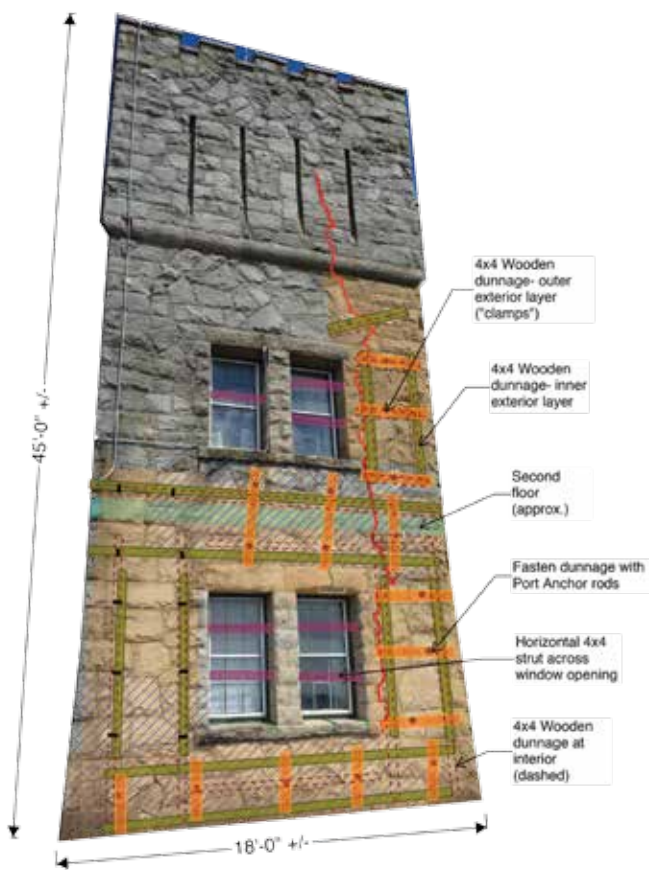
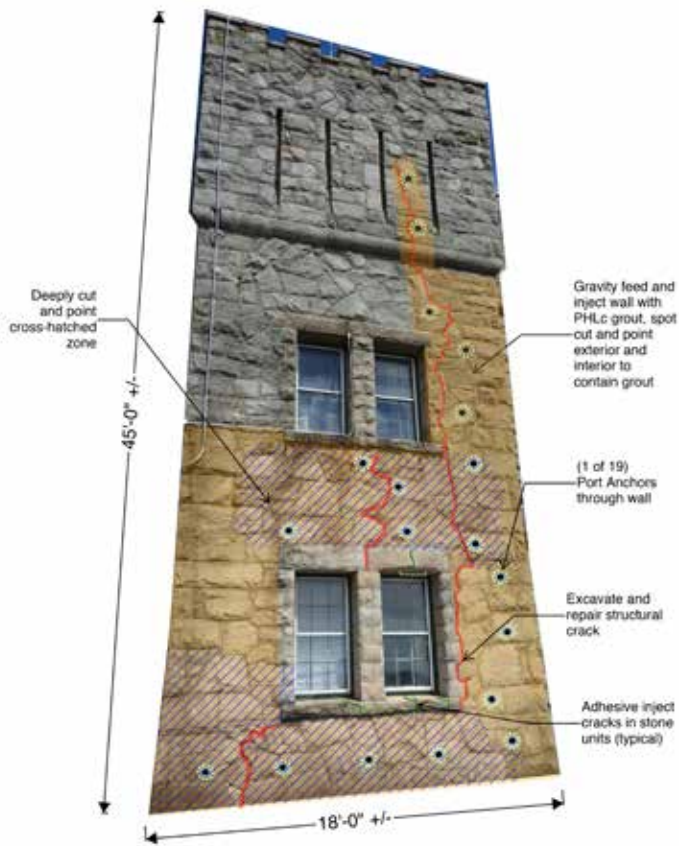


Fig. 9: Repairs and dunnage on west elevation/north half

cent of the measured core-hole lengths were found to be empty cavities and out of more than 50 cores taken not one single core was retrieved in a bonded condition.

Next, the mortar joints at the exterior were cut and repointed along with accessible, damaged mortar joints at the interior. Because of the presence of floor framing, wall returns, and in a few places interior finishes, a combination of single-ended and double-ended anchors would be used. Additionally, because of the extremely poor condition of the masonry, wooden dunnage was needed at both the exterior and interior.

Anchors were installed by inflating the fabric socks with a high strength grout, and the dunnage system was fastened to the exterior by rods that were threaded into recessed inserts in the ends of the anchors. After the anchor installation and dunnage system were complete (Fig. 9), grouting of the wall began, working from the bottom up using the port anchors as well as supplemental holes drilled into



Fig. 10: In-line injection piezometer



Fig. 11: Completed work before final wash-down

the interior. Grout lifts were limited to 3 ft (1 m) per day, and a system of pressure-limiting in-line piezometers (Fig. 10) was devised to avoid internal grouting pressure spikes when refusal was reached.

After the first round of grout injection was complete, several rounds of holes were drilled into the wall to confirm that it had been solidly filled. Where voids were encountered, the holes were then used for re-injection. After the walls were solidly filled, the dunnage and extension rods were removed, and the anchor holes were filled by bonding thin “biscuits” that were cut from the outer ends of the corresponding cores. A section of completed work is shown on Fig. 11.

CONCLUSION

The poor as-built condition of the Bristol Maritime Armory, and the more than 100 years of ongoing cracking and instability, is an extreme example of what can happen when cost-cutting short-cuts are taken during construction without regard to the troubled service life that might follow for the structure. The stabilization of the Armory is an illustration of the way that the technical challenge of a range of problems can drive the development of a new technology to help solve them.

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Bristol Maritime Armory Stabilization Bristol, Rhode Island

OWNER

The Town of Bristol
Bristol, Rhode Island

GENERAL CONTRACTOR

Tavares Construction
Bristol, Rhode Island

MASONRY RESTORATION CONTRACTOR

Folan Waterproofing and Construction
South Easton, Massachusetts

STABILIZATION ENGINEER

Structures North Consulting Engineers
Salem, Massachusetts

ANCHORING AND GROUTING SYSTEM

VoidSpan Technologies
Salem, Massachusetts



John M. Wathne, P.E., is the president and founder of Structures North Consulting Engineers, Inc., Salem, MA, which is celebrating its 20th year. John is a graduate of Lehigh University, and has a wide range of structural analysis and design experience related to historic building restoration, stabilization and renovation, with nearly all

structure types, and an emphasis on construction built before or during the nineteenth century.

Wathne is the founder of VoidSpan Technologies, LLC, was part of the technical development team for VoidSpan’s pozzolan-lime based grouting products, and is the inventor of VoidSpan’s patented multi-sock “VoidSpan Port Anchor,” which both ties and compositely bonds voided masonry together by serving as a grouting port.

He is the chair of the American Society of Testing and Materials (ASTM) Task Group C12.03.03 that developed ASTM’s “Standard Specification for Mortars for Existing Masonry,” ASTM C1713, and the primary author of its commentary, which is referenced in 60 countries. John is also the co-chair of the International Concrete Repair Institute (ICRI) 410 Masonry Committee.