Comments Based on an Examination of
Endicott Battery Historic Concrete at Fort Sumter National Monument
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1. Examination of a room within a 100 year old concrete structure, used for some years as a cistern, 99% sealed for 45 years, recently unsealed. This isn't posed as a question, but following are some general comments.

1.1 *Effect on Steel.* The continuous presence of the high level of water vapor inside the cistern room clearly modified the concrete in the ceiling and probably the walls in ways that encourages corrosion of steel. The cause and effect goes something like this. The pH of new concrete is high, typically between 12.5 and 14, depending on the cement chemistry. At this high a pH, steel won't corrode even if wet. Very slowly, atmospheric carbon dioxide will penetrate surfaces of concrete and chemically react with the calcium hydroxide component of hydrated cement paste and convert it to calcium carbonate (limestone). This causes the pH to drop to around 8. Steel corrodes at this pH. As mentioned, the rate of carbonation is slow, but does depend on the relative humidity of the concrete environment. It is extremely slow if the RH is near zero, and slow if the concrete is totally saturated. Under good carbonation conditions, the rate of carbonation is about 1" every 50 years, +/- depending on the permeability of the concrete to CO_2.

1.2 Clearly the conditions in the cistern were better for carbonation than in other similar parts of the structure that were not both sealed and containing water because the corrosion is much worse there. Now that this part of the structure has been dried out and the carbonation depth has pretty much progressed to the depth of the steel (apparently, judging from the corrosion), this corrosion will continue to progress, resulting in loss of structural competency of the steel and loss of surface concrete due to the expansive nature of corroding steel.

1.3 The loss of the steel and concrete may not have any serious structural implications for the structure. The steel was likely put there originally to support the load of the fresh concrete during construction, but you may need to get the opinion of a structural engineer to be sure of this. The situation can be restored by chipping off the concrete from the damaged area, cleaning the major loose corrosion from the steel, then replacing missing concrete with new concrete. If determined that loss of competency of steel is important, then new steel can be spliced in. Undamaged areas of the ceiling may be OK, but they may also be at or near the threshold of developing corrosion. You can determine this by having some shallow cores taken and determining the depth of carbonation. This not particularly complicated, but is a laboratory exercise.

1.4 *Other Effects*. Except for corrosion, I don't think the change from a constantly wet or damp condition to a drier condition will have major effects on the concrete. There will probably be some shrinkage that occurs, possibly causing some existing cracks to open up some. The interior of the concrete may never totally dry out. Cracks may be distributed out as a few 1 – 2-mm wide cracks across the surface or as a larger number of narrower cracks, depending on a number of physical features of the structure. Typical shrinkage could be as much as 1 to 2 millimeters per meter of concrete surface. In thick structures, they often won't penetrate completely through the structure, but will be confined to the general near surface zone where the maximum drying will occur. In an old structure, this will usually occur as a widening of any previously existing cracks.

2. Is water good or bad for 110 year old concrete?

2.1 *General Comment*. In general, water is neither good nor bad on old concrete. As discussed above, wetting and drying of concrete does cause some swelling and shrinkage, respectively, that may have some effects on existing cracks, or in some cases, cause some new cracks. But this doesn't destroy concrete unless loss of structural integrity results in a serious overload condition, which can result in concrete degradation. Pavements are particularly susceptible to this form of degradation.

2.2 *Benefits of Water*. Water is good for concrete at early ages because is allows the hydration of the cement to occur, depositing additional strength-bearing reaction products. This effect pretty much runs its course in the first year or so for modern concretes, and in the first several years for something like Rosendale-cement concrete. Concrete that has been wet for a long time will sometimes show deterioration, but this is either because some kind of dissolved salts make their way into the concrete with the water, or there is some water-requiring damaging chemical reaction potential in the concrete. We pretty much know the major of these.

2.3 *Sulfate Attack*. Sulfate salts are the major compounds that cause problems, but only in come concrete. Sea water contains enough sulfates to cause problems in concrete made with cements with very high contents of certain calcium aluminate compounds. This is the case with modern Type I portland cements. Type II and Type V cements have restricted amounts of the critical calcium aluminates. I don't think Rosendale cement is one of the sensitive ones. If it were, I think you would probably have already seen considerable deterioration down at the foundations of the structures. The Na in sea water can also cause some problems, as discussed below.

2.4 *Alkali-Aggregate Reaction (AAR).* There are a couple of chemical reactions that sometimes occur among the ingredients of concrete that are facilitated by water. One is the well know alkali-aggregate reaction. The major subclass of AAR is alkali-silica reaction (ASR). This occurs when certain siliceous aggregates react with the high pH pore fluid in concrete to form expansive silica gels. The high pH is mostly caused by the interaction of calcium hydroxide and sodium/potassium salts in the cement. Ingress of Na from sea water can also contribute to this. If the reactive combination existed in the 110 year old concrete, I'm pretty sure we would have already seem the damage in areas that stay wet a lot. I didn't see any evidence of this.

2.5 *Unsoundness.* The other internal chemical reaction that was somewhat common in early portland cements is the expansion that occurs when magnesium oxide of a particular form (called periclase) reacts with water to form magnesium hydroxide and/or a similar reaction involving calcium oxide (free lime). Like ASR, these reactions form expansive compounds. Collectively they are called "unsoundness" in cement. These are a relatively slowly developing reactions, but I'm pretty sure that if the high Mg content of Rosendale cement was a problem, it also would have shown up by now. There are also laboratory tests that are run to detect this problem in new cements (autoclave test). Both of these reactions are very rare in modern-day cements.

3. We have sealed the exterior of our Endicott batteries with a modern roofing system. In the short term this has been good. Will this prove to be bad in the long term (25 years)? I don't see a long-term downside. As discussed above, it will cause some changes in moisture content, which will have some effects in the way of minor shrinkage, but this shouldn't cause any major effects.

4. Should we treat (preserve) Rosendale cement based concrete differently than OPC based concrete? I don't think so. I'm going to contact a person I've met who is on the inside of the Rosendale cement business to be sure I'm not missing a detail on this.

5. What happens to Rosendale concrete after 110 years of curing and exposure to maritime environment? What's going on with cryptoefflorescence?

5.1 I don't know what cryptoefflorescence is. The parts of the word suggest hidden efflorescence. Anyway if we mean the efflorescence we see on some of the vertical walls, then the following applies.

5.2 *Efflorescence*. Efflorescence is a normal, non-damaging, phenomenon that commonly develops in any concrete or masonry that's exposed to water in one area (typically roofs and terraces), which then drains through small cracks and exits at another spot (i.e. seepage paths). Soluble salts are leached from the cement fraction during this seepage and then is deposited by evaporation near the exit point. Some of the salts are soluble in water and can be washed off. However, calcium carbonate is usually a major component of efflorescence and is hard to wash off with water. Dilute muriatic acid (about 10%) and a brush will usually work well to periodically remove it if you think it gets to be unsightly. The dilute acid will not attack mortar or concrete surfaces significantly, but the full-strength acid as it comes from the hardware store will, avoid full-strength acid.

6. What are the mechanisms that cause concrete of this type and in this environment to deteriorate over time? The Charleston environment is not especially aggressive, but there are a few things.

6.1 *ASR & Chemical Reaction*. These are discussed above, and do not appear to be active.

6.2 *Freezing and Thawing*. Concrete that isn't air entrained will tend to degrade as a result of repeated cycles of freezing and thawing when the concrete is saturated with water. Concrete placed before the mid 1940's was rarely air entrained. Charleston isn't a particularly severe freeze-thaw exposure, but of course these events do occur. The intensity of the cold is fairly mild, so the damage is usually confined to surfaces that haven't had a chance to dry at least a little after a rain. Very level surfaces or surfaces that have some low spots that have a tendency to dry slowly are susceptible. Surfaces that have a slope so that they tend to drain well don't usually show too much of a problem except in areas where snow and ice accumulation are common.

6.3 *Thermal and Wet/Dry Cylces*. Some of this was discussed above in the context of shrinkage. Changes in both temperature and moisture, as occur seasonally, will cause cyclic volume changes in the concrete. These aren't very large, but they are large enough to cause existing cracks and joints to open and close, or perhaps shift in other dimensions. This will sometimes cause some abrading of the crack surfaces.

6.4 *Joint and Crack Maintenance.* Due to the above mentioned movement associated with wet/dry and temperature cycles, cracks and joints will tend to accumulate incompressible material when they are at their maximum width. Then when they tend to close due to the change in conditions, the material will not allow the joint or crack to close. This results in causing the entire block of concrete or masonry to then move because the forces caused by the volume changes associated with moisture and temperature changes are very strong. They can result in considerable secondary damage if the structures are confined in any way against this movement. Confinement can be surface friction from the foundation or by other structures that are adjacent to the cracked or jointed structure. This can be serious as the forces accumulate over a period of years (usually) and sometimes causes major fracturing of the concrete or damage to adjacent structures. The most susceptible joints or cracks are the ones on horizontal surfaces because the incompressible material isn't washed out by rain. Vertical joints and cracks are less susceptible. Horizontal joints and cracks should be sealed and inspected periodically. If they do get full of incompressible, these usually can be cleaned out and resealed.

7. **Examination of contemporary Rosendale natural cement used to repair historic concrete.** I'm not exactly sure what is being asked here. This seems to be similar to Question 10, on testing modern Rosendale cement. Or, maybe you are asking about things to look out for when using modern Rosendale cement for repair applications. I'll briefly speak to the latter and address the former in Question 10.

7.1 *Basic Properties.* In repairing structures using Rosendale cement, the things to look for are pretty much like in any concrete and mortar work. The basic requirements are that the cement has a setting time under the conditions of use that is suitable to the job (but not excessively long), that the mixture proportions are correct and consistent during the job, and particularly that water content doesn't get out of control. Hot and/or dry conditions, and cold weather each present special problems to placing concrete and mortar that must be recognized.

7.2 *Hot Weather.* In hot and/or particularly dry weather, the mixing water is easily lost from the fresh concrete/mortar. Hot concrete and/or high wind are particular problems, although low humidity and high air temperatures also contribute. I could go on for quite a while on this one. ACI 305 covers this subject. Probably an example of this problem is in the Rosendale mortar used to cover the steps in the battery across the street from the park HQ. Notice the abundant closely spaced cracks.

7.3 *Cold Weather.* Cold weather is less of a problem except that setting time and strength gain are slowed down greatly. The greatest danger is a freezing event during the first day or so after placing. In a location like Charleston, this is relatively easy to deal with. A sheet of plastic covering the new placement will usually buffer a moderate freezing event. ACI 306 covers cold weather concreting.

8. What is best product to use to "white wash" the walls of interior passageways? I think it is generally agreed that lime washes are the best material because of the high levels of moisture permeability. As above, I don't think the moisture really hurts the concrete, unless there are one of the known water driven deterioration scenarios, but sometime impermeable coatings will blister if there is much water in the concrete that 'wants' to get out. Mildew can sometimes also be a problem when an impermeable membrane keeps a space wet. I would think this to be most likely with an exterior waterproof membrane.

9. The Schmidt hammer is used to test the hardness of concrete in-situ. I need a tool to test the hardness of brick mortar in-situ. This is a difficult problem in practice since I don't think there is a test method specifically designed for the unusual condition of in-place mortar.

9.1 *Schmidt Hammer (aka rebound hammer).* The concept of a Schmidt hammer (ASTM C 805) is probably useful for testing in—place mortar. However, between the relatively low strength of masonry mortar and the way a masonry wall is poorly supported against the impact of the hammer, the test result usually doesn't even register on the instrument. This instrument is designed for much more testing much more rigid materials in a structurally well supported environment.

9.2 *Windsor Probe.* Another test concept is the Windsor Probe (ASTM C 803). The concept is to apply a sudden force onto a nail-like penetrator, then measure the depth of penetration. This requires calibration with materials of known properties. The method says that configurations can be had that cover the strength range from about 400 – 4,000 psi, but I'm not sure the configuration of a mortar joint would represent a suitable test configuration. One would really need to borrow one of these and try it out. Also, I suspect that many historic mortars have strengths less than 400 psi.

9.3 *Other Testing Approaches.* When I was with the Corps, we tried to take cores or to saw small specimens from mortar joints, then to test them as small, but conventional, test specimens. Coring is difficult with low strength mortars because the forces involved often cause the mortar to crumble. I think very delicate sawing could be made to work, but it would probably require securing some test equipment that was suitable for preparing very small specimens. Most specimen preparation and testing equipment in a standard cement and concrete lab is way too heavy duty. The specimen prep equipment may exist at Clemson, but whether the equipment required to measure low loads and small strains may not be there.

10. Lab testing of contemporary Rosendale materials.

10.1 *ASTM C 10.* It's reasonably easy to test Rosendale-based materials using the same test methods and equipment used for portland-cement based materials. Specification ASTM C 10 describes this.

10.2 *Types.* The specification covers two types of cement: "Natural Cement" and "Quick Setting Natural Cement." The former must set no sooner than 30 min, and the latter must set in no less than 10 minutes and not longer than 30 minutes. Of course these are at laboratory temperatures. These properties are very sensitive to temperature, so field performance may vary.

10.3 *Strength.* Mortar strength requirements are the same for both types: 510 psi at 7 days and 1020 psi at 28 days. These are minimum strengths. It is likely that the actual strengths would be quite a bit higher unless one of the options for a coarse-ground cement are invoked. The specification gives historical information on particle fineness levels common in natural cements from 1904 – present. These optional levels of fineness can be specified, although a given producer of natural cement may or may not actually agree to do this, probably depending on the economics of the matter.

10.3 *Other Requirements.* Other requirements include an autoclave test (to insure that unstable forms of Ca and Mg are not present), a loss on ignition (to insure that not too much moisture has crept into the cement), an insoluble residue limit (to insure that the supplier isn't contaminating the cement with inert fillers), and a limit on sulfur trioxide (to insure that there is no excess SO3 that might cause a later age deterioration problem).

11. Other Thoughts. Following are some things that come to mind that you didn't ask about, I don't think.

11.1 *General Repair Concepts.* My understanding of current thinking on repair and restoration of any structure is that the new materials have physical properties that reasonably match those of the existing concrete, and that there are not any damaging chemical interactions involving the new material. The major physical properties are thought to be strength, modulus or elasticity, and coefficient of thermal expansion. Strength and modulus are pretty highly correlated, so people often design around strength. The problems are less acute if a new structure is built up against an older structure, because the two structures are normally isolated with appropriate joints anyway. It's in patching applications that the problems normally develop. Major differences in the above properties will cause them to respond to temperature, moisture, and loading in different ways, so that the two materials will tend to either separate (in spite of good bond strength) and/or damage each other.

11.2 *Pre-construction Lab Work.* My understanding is that the manufacturers of Rosendale Cement have targeted the properties to reasonably match those that exist in the historic structures. I can imagine that this might be a little tricky because the product seems likely to have changed over the decades-long period of its original availability – but maybe this wasn't that much. Ideally one would be able to determine properties of the original in-place material and match these by adjusting the proportions of cement, sand, and water (or other materials, such as fly ash). This would require some pre-construction lab work.

11.3 *Hardness of Modern Rosendale Cement.* Some comments were made that some of the Rosendale Cement in the Ft. Moultrie/Sumter area was very hard. It wouldn't be surprising that it would be much harder than a lime or hydraulic lime material. The latter are notably soft, even after decades. Rosendale Cement is a hydraulic cement with a lot of properties similar to portland cement. It still may be weaker than portland based materials, but this difference won't be perceptible to the touch when it gets beyond a certain point. Still, it's possible that Rosendale is too strong for some brick - depending on the brick – and maybe wasn't the best material in the first place.