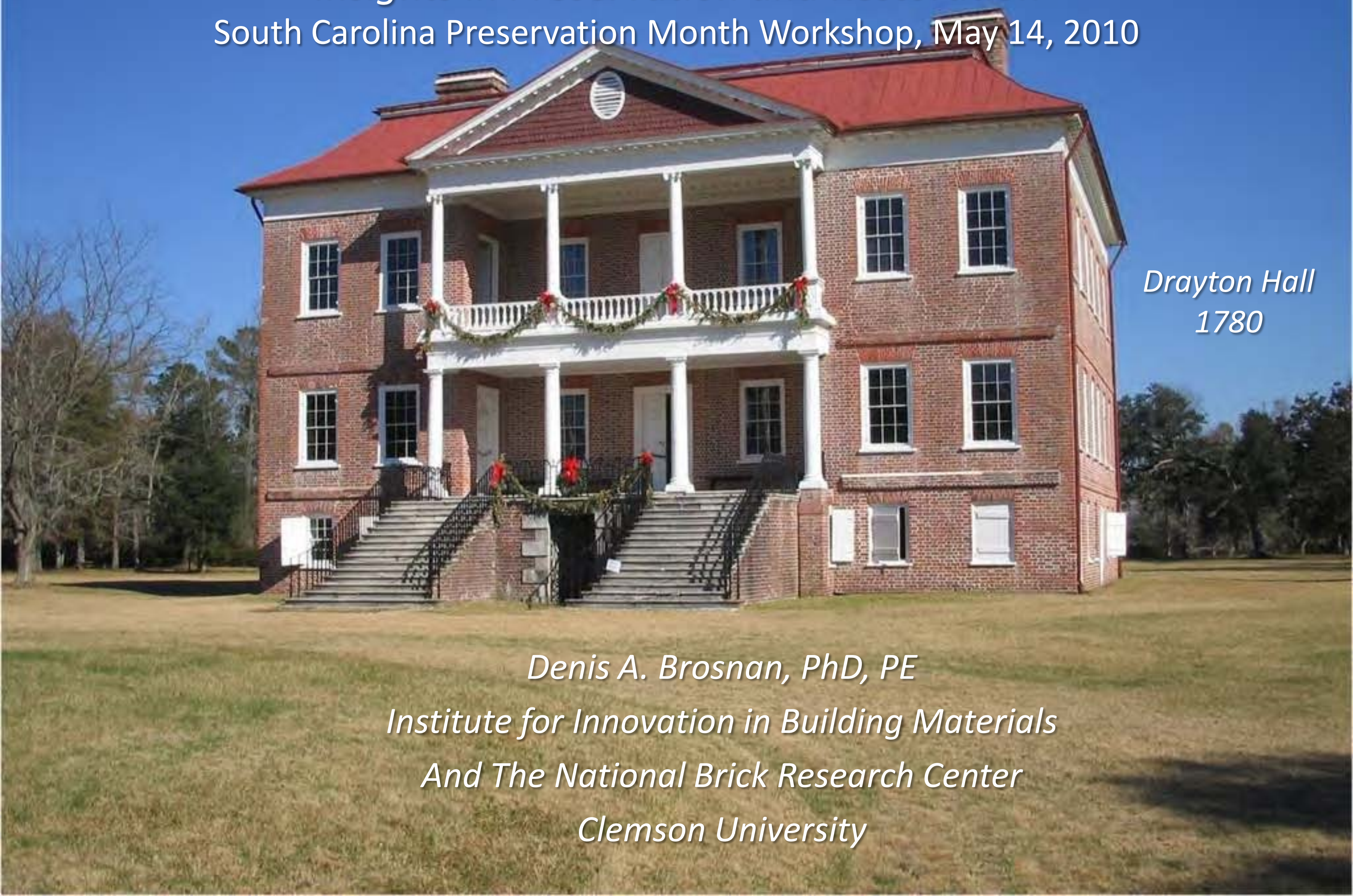
South Carolina Brick Masonry - Green Forever

Insights in Preservation and Restoration

South Carolina Preservation Month Workshop, May 14, 2010



Drayton Hall
1780

Denis A. Brosnan, PhD, PE

Institute for Innovation in Building Materials

And The National Brick Research Center

Clemson University

Today's Five Part Presentation

1. *Something Old – Something New* in "Sustainability".
2. *First Brick Made at Mount Pleasant Since 1860. Grad students from USC make bricks in 2010.*
3. *Bricks.*
4. *Mortar.*
5. *Case Studies.*

PART 1

Something New

Environmental Movement: From the Environment is a “Sink” To Conservation → Protection → Sustainability

Sustainability

“All humans should be able to enjoy a decent level of well being taking from nature sustenance without interfering with the continuity of nature and without harm to other life forms on the planet.”

AIA’s Environmental Resource Guide (1996)

Founder in 2001 of Johnston Design Group, Scott Johnston leads an architectural firm that is dedicated to environmentally sustainable design. The firm has been recognized nationally with numerous awards and publications for excellence in sustainable design. The practice offers sustainable design consulting and the authoring of green design guides, conservation development planning, historic preservation and adaptive reuse consulting, and architectural services for a variety of education, mixed use, affordable housing, and custom residential projects.

Scott Johnston AIA, Greenville, SC

U.S. Green Building Council

- National nonprofit organization based in Washington, DC
- Diverse membership of organizations
- Consensus-driven
- Committee-based product development
- Developer and administrator of the LEED™ Green Building Rating System

ASTM Sustainability Standards:

E 2432-05, “Standard Guide for General Principles of Sustainability Relative to Buildings”.

E 2129-05, “Standard Practice for Data Collection for Sustainability Assessment of Building Products”.

E 917-05, “Standard Practice for Measuring Life-Cycle Costs of Buildings and Building Systems”.

Do these standards accurately reflect the *longevity* of masonry materials?

Guide for environmental performance claims.

Example of an Industry Association Publication

Brickwork is durable and . . . Brick building can be and are reused. . .

However, Tech Note 15 seems to discourage use of salvaged bricks.

Sustainability and Brick

Abstract: This *Technical Note* discusses sustainability and sustainable design and their relationship to brick manufacturing, use and recycling. Sustainable practices in manufacturing are identified, as are ways to utilize brick as part of sustainable design strategies. Ways that brickwork can be used to earn points in the LEED and other green building rating systems also are identified.

Key Words: environmental impacts, green building, LEED, life cycle assessment (LCA), recycled content, resources, sustainability, sustainable design, thermal mass, volatile organic compounds (VOCs).

SUMMARY OF RECOMMENDATIONS:

- Sustainable design balances environmental, economic and societal goals. It is more than just a certification from a rating system
- Brick is made from abundant natural resources (clay and shale) and is readily recycled for use in the manufacturing process or other uses
- Brick manufacturers address sustainability by locating plants in close proximity to mines; incorporating waste products and recycled materials into brick; reducing energy use, water use and atmospheric emissions; and utilizing landfill gas and other wastes for fuel
- Brickwork used in sustainable designs can provide structure, finish, acoustic comfort, thermal comfort, good indoor air quality, fire resistance, impact resistance and durability, all in one product
- Brickwork can help meet requirements of many certification rating systems in the areas of development density, storm water management, heat island effect, improved energy performance, building reuse, construction waste management, materials reuse, recycled content and regional materials
- Brickwork can contribute to improved indoor air quality by eliminating the need for paints and the resulting volatile organic compounds (VOCs) and by eliminating a food source for mold
- Brickwork is durable, having a life expectancy of hundreds of years. Brick buildings can be and are reused, thereby distributing their environmental impact over an extended life span

INTRODUCTION

"Sustainable design" is a term that has entered the vernacular of building design and construction. As more buildings are designed and constructed using sustainable design principles, the need for information on building products and their sustainable design features also grows. In assessing the sustainable attributes of building products, consideration must be given to how the product is manufactured, used and disposed of. This *Technical Note* provides information on brick usage, manufacturing and recycling as it relates to sustainability.

WHAT IS SUSTAINABILITY?

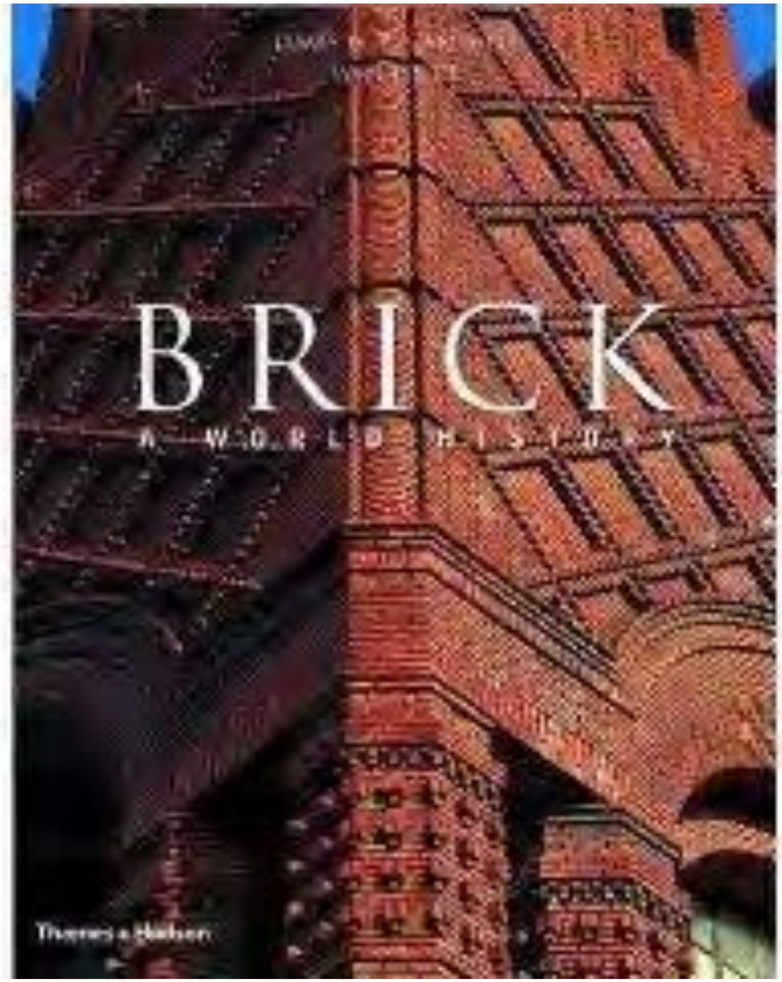
Sustainability is defined as *"meeting the needs of the present without compromising the ability of future generations to meet their own needs"* [Ref. 2]. Sustainable buildings are designed in a way that uses available resources efficiently and in a responsible manner, balancing environmental, societal and economic impacts to meet the design intents of today while considering future effects. Sustainably designed buildings are energy-efficient, water-efficient and resource-efficient. They address the well-being of the occupants by considering thermal comfort, acoustics, indoor air quality and visual comfort in the design. They also consider the impact of a building's construction, operation and maintenance on the environment, and the environmental impact of the building's constituent materials. A sustainably designed building considers all of these aspects through the entire life cycle of the building, including its operation and maintenance.

Often the tendency is to focus on one aspect of sustainable design, such as energy use or environmental impacts. This approach leaves out other equally important elements necessary for true sustainability. Truly sustainable design is best described as achieving the "triple bottom line," that balance of environmental goals, societal goals and economic goals.

A high-performance, sustainable building design should include accessibility, aesthetics, cost-effectiveness, durability, functionality/operation, productivity of occupants, security and safety, and environmental performance.

People in 1886 took bricks from the ruins for construction of their buildings.

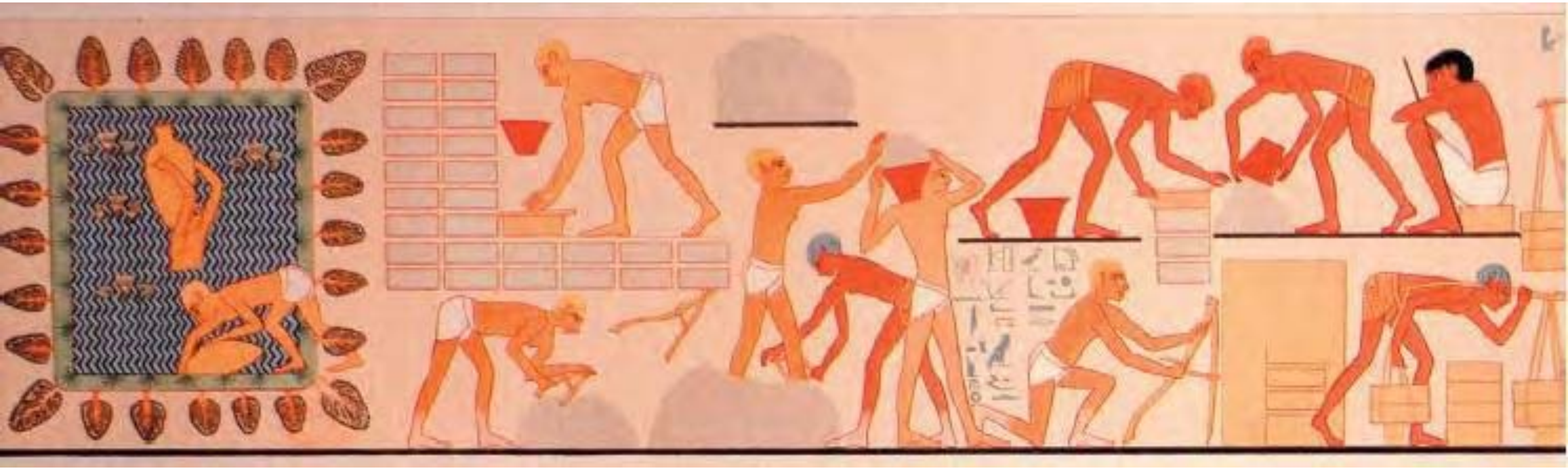
All About Clay Bricks



Prof. James Campbell's Book
Has Been Available for About Five Years

Something VERY Old

The Egyptians were smart! They knew how to fire pottery to meet specific purposes.



The world's oldest mud bricks were discovered in Jericho near the Dead Sea (about 8300 to 7600 BC) with dimensions of 260 X 100 X 100 mm. Later bricks from the same site were longer and flatter (400 X 150 X 100 mm). The picture above shows an image from the Tomb of Rekh-mi-Re (1450 BC). The Egyptian bricks contained straw to strengthen the bricks and to reduce drying shrinkage from the alluvial clays.

These were possibly the world's FIRST composite materials.

First Fired Bricks – Mesopotamia

The earliest fired bricks were found in Mesopotamia (Iran) made about 5000 BC and used to form a drain. Pottery was developed about 7000 – 6000 BC.

Thus, water resistance ("durability") was a first reason to make fired bricks, as the area had frequent floods.

Nevertheless, records from 2003 BC indicate fired bricks were 30 times more expensive than mud bricks.

According to Campbell, "It took a civilization of much greater sophistication to … afford fired bricks".

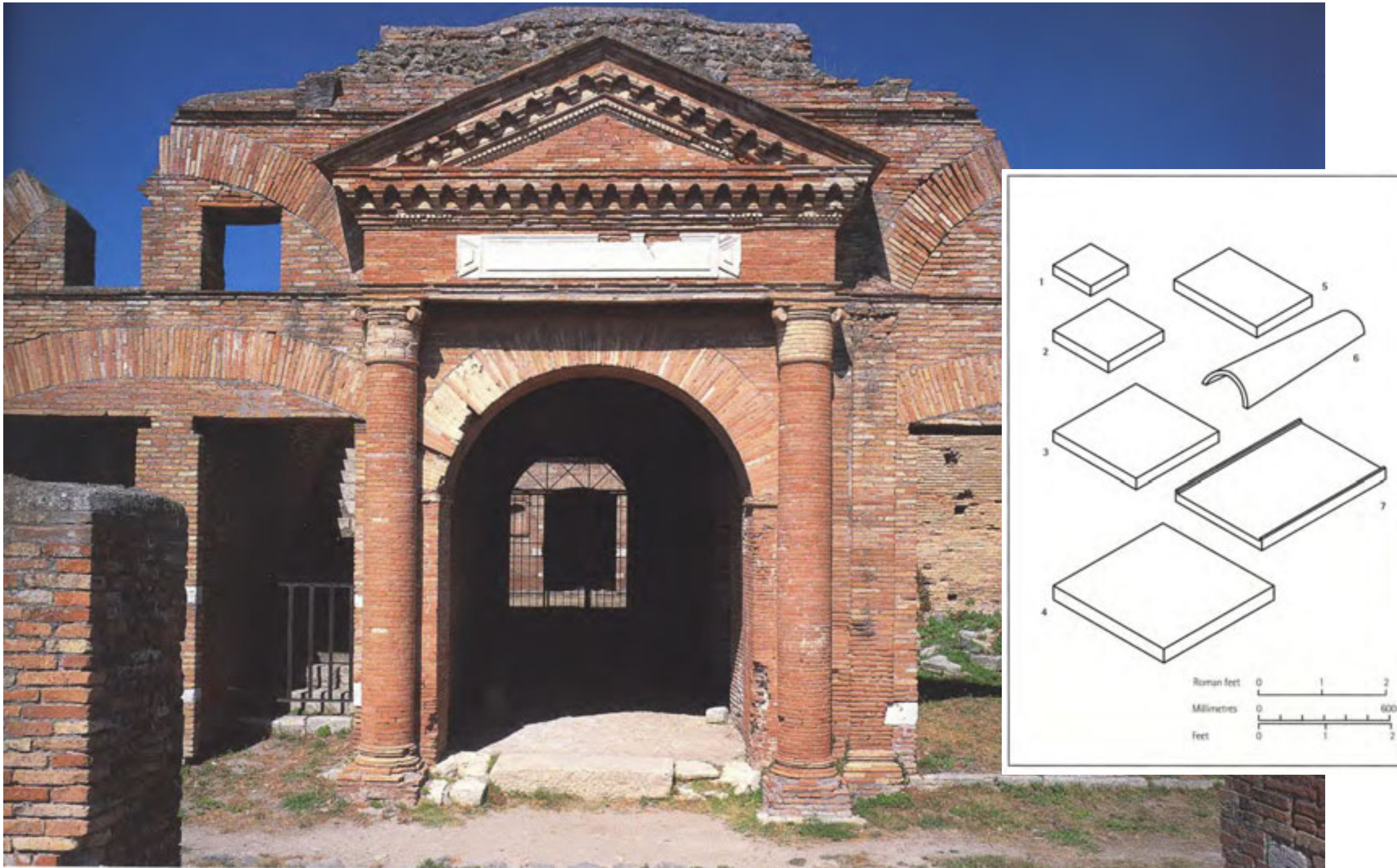
James Campbell in *Brick, A World History (2003)*

Ziggurat Choga Zanbil (1250 BC)

Palace Throne Room, 604 – 652 BC

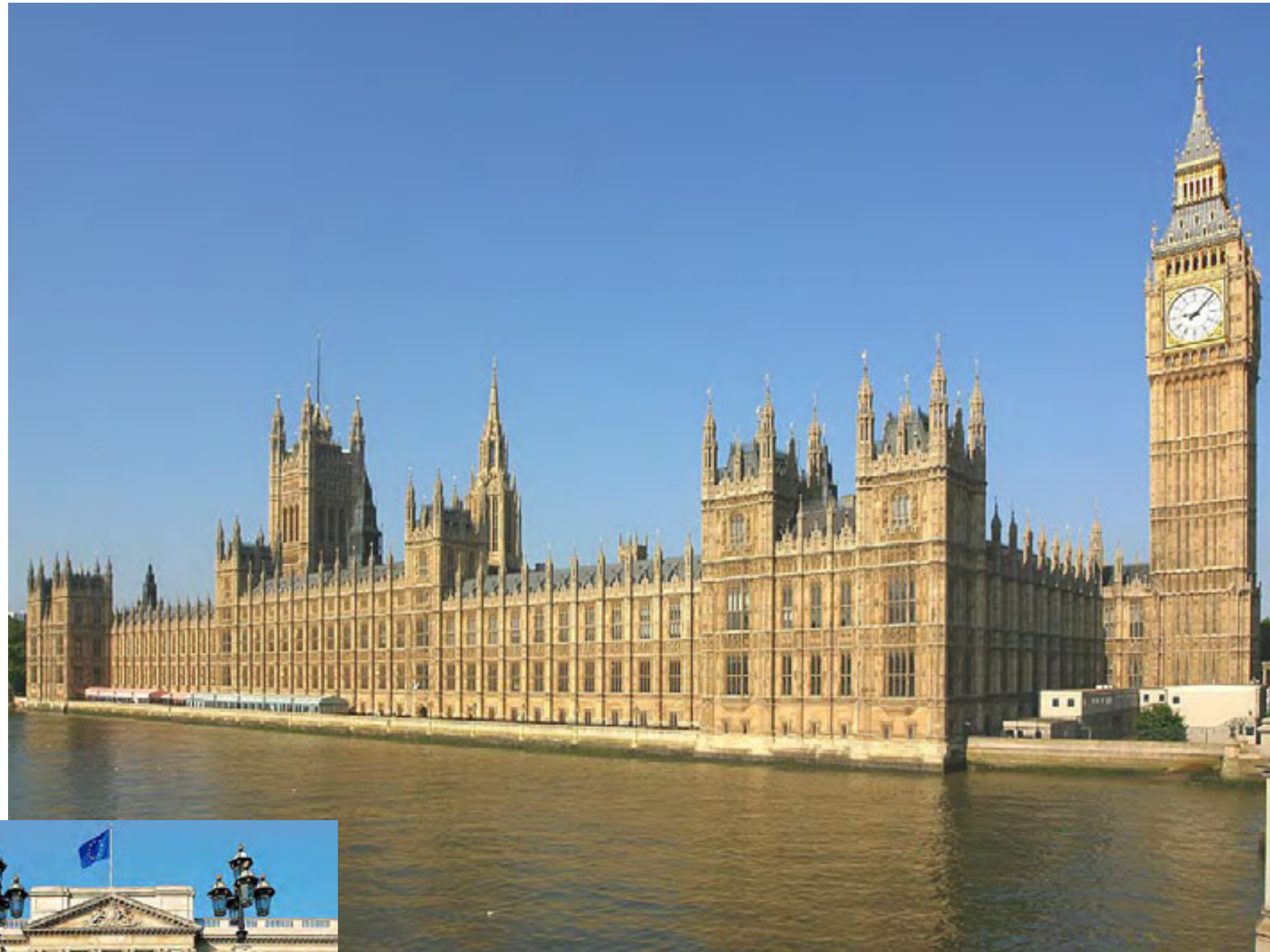
Brickmaking was greatly improved by the *Babylonians*, who developed glazed bricks. Fired bricks in Babylon remained expensive at about five time the cost of mud bricks.

The Romans



Roman Tomb, 150 AD (Inset – Roman Brick Shapes), Notice the color of the bricks as “salmon”. This led to the *tradition* of coating bricks with stucco in Southern Europe.

Britain!



Is this a brick masonry building?

Bricks Imported to the Colonies

Near McClellanville, SC

"The body of the church is built of brick imported from England", www.stjamesec.org/brickchurch.html.

THIS IS UNLIKELY!

A large ship could carry about 6000 bricks. While bricks were imported into New York, particularly from Holland (yellow and black bricks), most claims of imported bricks seem to be claims of a status symbol coveted in the 1700's. See Houses of Bricks Imported from England (1904).

Fire Resistance Becomes a Great Motivator: London (1666), Charleston (1861), Chicago (1871), Clemson (1894), San Francisco (1906), etc.

Beginnings in Charleston

Loading Levy at Lexington Plantation

Something Old/Something New

- To understand "*Greenness*" of brick masonry, you <u>first</u> consider the proven durability of fired bricks. Buildings 2000-3000 years old are still standing.
- Early motivation to use fired clay bricks included durability – water resistance and fire resistance.
- The Romans perfected brickmaking – establishing methods to make durable brick for Northern Europe by firing them "harder".
- A thriving brick industry developed in South Carolina in the 1700's along the coast.

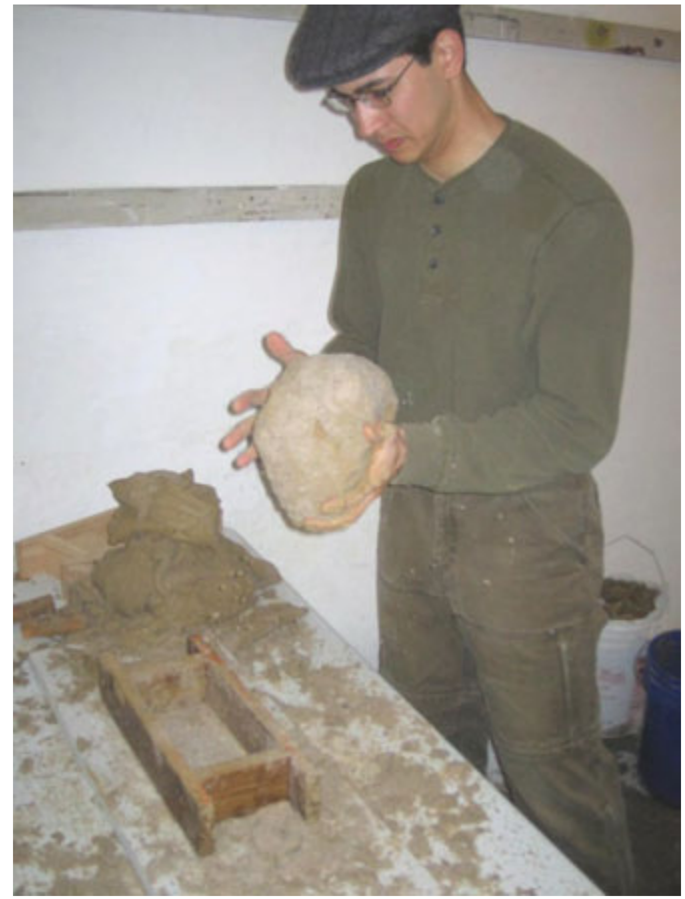
Questions on Part I?

Part 2

USC Grad Students Make Bricks on Lexington Plantation

One goal of this project was to illustrate methods to make restoration bricks for Fort Sumter National Monument. Students - Sarah Swinney and Lee Durbetaki.

Tempering the Clay



Lee Ready to "Throw" a Brick

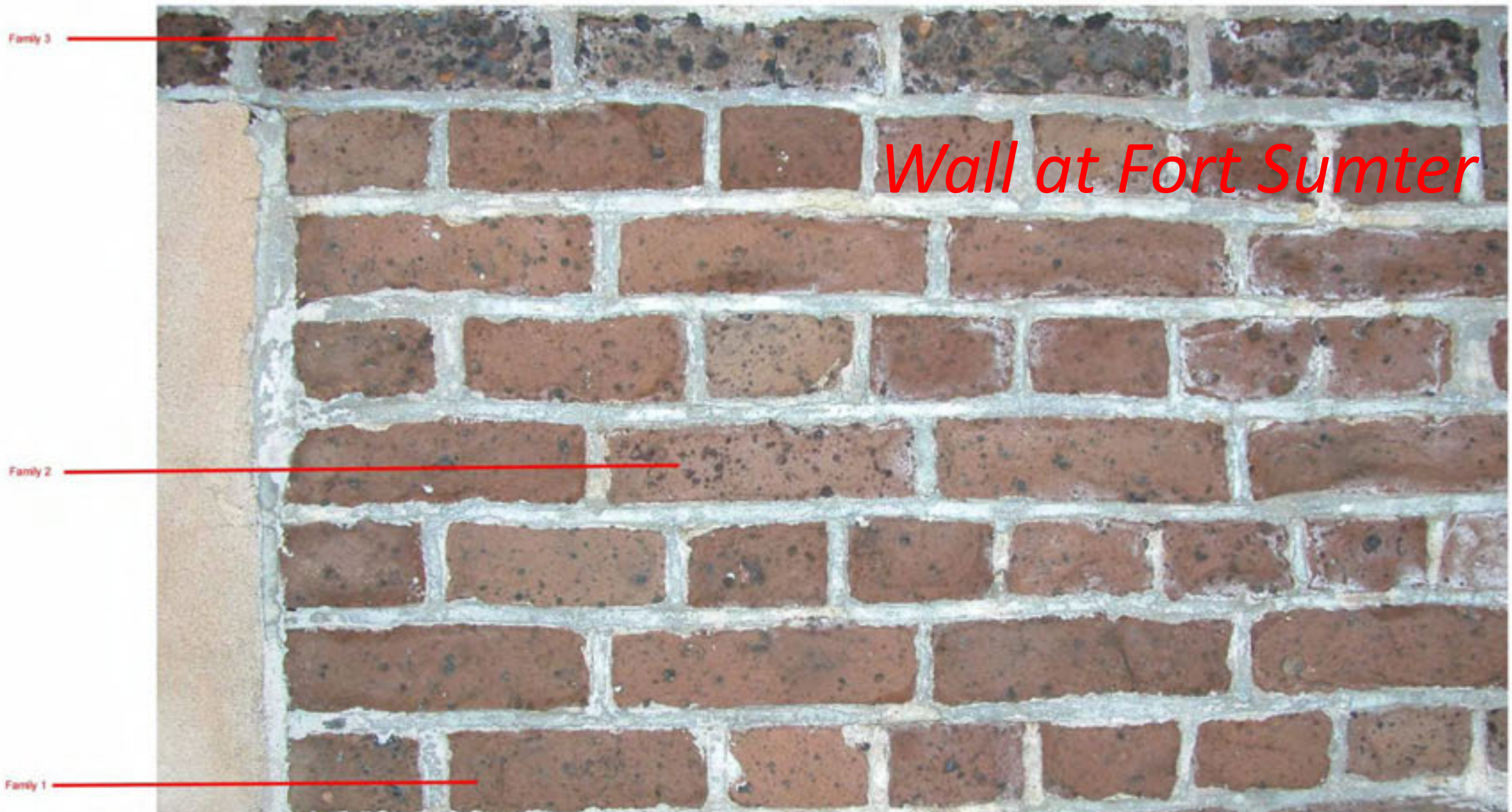
Sarah and Lee were doing a special project For Dr. Bob Weyeneth, Professor of History, Director – Public History Program, University of South Carolina.

Skove Kiln, Photo in the Charleston Museum

Skove Kiln, Colonial Williamsburg

Sarah and Lee's Bricks in a Kiln at Clemson

Wall at Fort Sumter



USC Student's Bricks

Questions on Part 2?

Part 3

Some Key Properties of Bricks

Property	Originates From	Consequence
Strength	Partial vitrification in firing.	Load bearing capacity. Indicated by “ring” or “thud”.
Absorption	Porosity in the fired brick.	Assists in mortar adhesion, but excessive absorption leads to durability concerns.
Color	Mineral constitution of the brick (chemical analysis).	Red bricks contain hematite (Fe_2O_3), black bricks contain magnetite (Fe_3O_4), and yellow bricks (lime). White bricks contain little iron oxide.
Soluble salts	Soluble constituents in the fired brick (or mortar).	Discoloration called efflorescence.
Durability	Too many “fine pores” in the brick (Those generally less than about 5 microns).	Freezing of water or salt saturated brick causes “spalling” in the wall.

Comparing Modern and Old Brick Properties

Property	Bricks Made Before ~1900	Modern Molded Bricks
Compressive Strength (CS), psi	*Commons*: 2000-4000 *Facing Bricks*: 4500-6800	5293 Average (σ=1822 psi)
ASTM C216 SW Specification on CS		3000 Average (2500 for any individual unit)
Cold Water Absorption (CWA), %	Commons: 7 – 16 Facing: 7 - 15	< 14 (implied); Have different specs for SW and MW bricks.
Boiling Water Absorption (BWA), %	Commons: 9-23 Facing: 11-19	< 17 (average) and < 20 (for any individual unit)
CWA/BWA (C/B or S)	Commons: 0.67-0.93 Facing 0.66-0.91	< 0.78 Average < 0.80 (for any individual unit)

Durability concerns for old brick usually involve high absorptions and high CWA/BWA.

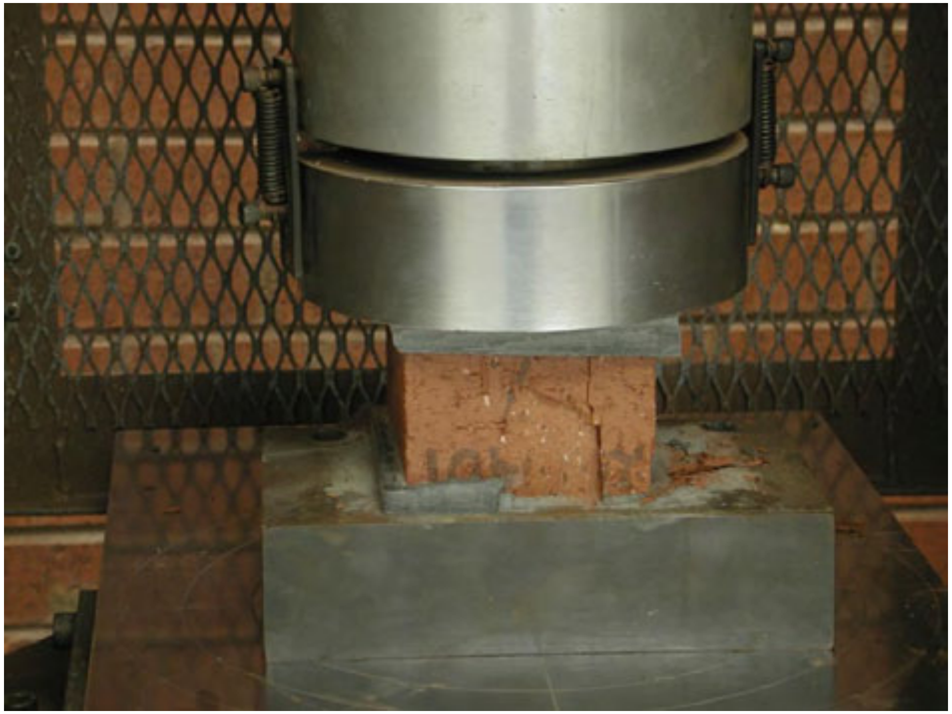
Brick are fired to develop a glass phase that serves to bond particles together permanently. This phase is primarily responsible for the durability of bricks.

Bricks are *first characterized* by their absorption properties (cold water absorption or CWA and boiling water absorption or BWA).

The ratio CWA/BWA or C/B reflects the pore structure of the brick and is related to freezing and thawing durability.

Most people are very concerned with compressive strength. It requires further consideration.

SAMPLE	Lexington Plantation (Modern)	Fort #1	Fort #2	Fort #13	Fort #31
Family	1250ºC firing temp.	2	1	3	4
XRF					
Al_2O_3	12.27	10.56	7.01	7.71	7.25
SiO_2	78.32	80.41	78.74	77.23	82.44
Fe_2O_3	5.53	4.00	3.49	6.07	4.14
TiO2	1.23	1.33	1.01	1.41	1.24
MgO	0.42	0.57	7.44	0.49	0.86
CaO	0.60	0.59	0.59	0.74	0.97
Na_2O	<0.5	<0.5	<0.5	<0.5	<0.5
K_2O	1.17	1.34	0.57	1.55	1.29
LOI	0.30	0.47	0.48		
Other					
XRD	Q,T,C,S	Q,T,C,A_3S_2	Q,T,C,A_3S_2	Q,T,C,A_3S_2	NA
Physical Properties					
CWA	8.47	15.26	18.64	13.86	19.59
BWA	17.81	21.05	23.43	23.54	24.95
C/B	0.57	0.72	0.80	0.59	0.79
Crushing Strength	4386	3556	NA	NA	NA
Porosity and Density					
BD	2.02	1.62	1.57	1.61	1.52
AP	29.04	34.18	36.76	35.93	38.01
Fraction >10μ, %	58.52				
Fraction, 1-10μ, %	37.11				
Fraction <10μ, %	4.37	8.4	1.9	4.4	9.4



Compressive Strength is measured by loading the brick to failure (left).

The compressive strength is the load at failure divided by the area of the loaded face.

In the process, the brick tends to slightly become “pancake shaped” resulting in tensile cracking.

Most old hand-made bricks have a compressive strength of 2000 – 3000 psi (lb/in^2). The reason for the range in properties is the uneven heat distribution in skove kilns. It was the usual practice to sort bricks by color and/or “ring” with light colored bricks called “commons” – for use in interior locations. The bricks that had experienced higher temperatures were classified as facing bricks and always used on the exterior. The average load on individual bricks in a wall is less than 25 psi (1.25% of strength).

There is no exact relationship between durability and compressive strength! Usually the durability is best estimated using the water absorption characteristics.

Other Brick Considerations in Restoration:

Modulus of Elasticity – the ratio of stress to strain or an index of “stiffness”; Restoration bricks should *not be* stiffer than the majority of bricks on the structure. The method of forming and the degree of firing affect stiffness.

Water Vapor Permeability – the rate of vapor transmission is usually high in old bricks due to their high porosity. Very dense bricks, called “clinkers”, or paving bricks usually have low water vapor permeance. This property is estimated by some people using an index called “capillarity”.

Color – it is obvious that restoration units must match the color of bricks in the host structure. Color differences are easily noticed.

Surface Texture – hand molded bricks have a surface texture unlike any machine made bricks.

Dimensions/Out of Square – an obvious match is required.

Thermal Expansion – the bricks on Ft. Sumter have twice the thermal expansion of normal clay bricks due to their very high sand content.

Most Clays <u>Darken</u> As Temperature Is Increased

The reason is the chemical change transforming red iron oxide progressively into black iron oxide.

Brick produced before ~1900 exhibited a wide range in color due to the non-uniformity of temperature in updraft kilns, i.e. clamps or field kilns. Color is thought to reflect quality of bricks – as in English "Engineer bricks" that are typically "blue-black" in color.

Fe_2O_3

hematite

Fe_2O_3
+
Fe_3O_4

Fe_3O_4

magnetite

Color darkening can be accomplished with temperature AND flashing.

Questions on Part 3?

Part 4

What is a Mortar? *A mortar is a mineral mixture with water forming a cohesive mass, which when applied to masonry units develops strength or hardens through chemical and physical processes.*

Functions of a Mortar:

- *Assuring a uniform stress distributed over "rough" brick surfaces.*
- *Leveling*
- *Adhesion*
- *Filling Gaps between Masonry Units*
- *A **sacrificial component** of brick masonry from a restoration perspective*

Is Mortar Required in Masonry Construction? *Most cathedrals in Europe were constructed without mortar before 800 AD – the stones used were so perfect in dimension that they were simply set one on top of another. Later, mortar became important for leveling of courses in masonry units of imperfect dimensions. It is reported that mortar was used in construction of the Great Pyramids to minimize the chances that Egyptian workers would break their toes.*

Filler + Plasticizer + Binder + H_2O = *Mortar*

Filler	Plasticizer	Binder
Provides "body", compressive strength, and limits shrinkage.	Provides "flow" or "spread ability" (using a trowel).	Provides permanent strength or "hardens".
Materials: Sand Shells Rock dust Brick fragments Sawdust	*Materials:* Clay Lime	*Materials:* Natron, Pozzolan, Gypsum/Anhydrite, Ash, Feces, Resin/tar, Lime, Portland cement

Proportions by volume:

3-7 Parts	+	¼-2 Parts	+	0.1-1.0 Parts
Filler		Plasticizer		Binder

Mortar Properties

- Compressive Strength
- Density/Porosity/Pore Size Distribution
- Modulus of Elasticity
- Water Vapor Transmission/Permeability
- Chemical Composition
- Mineralogical Composition
- Color
- Chemical Resistance/Salt Resistance
- Thermal Expansion

Mortar – Historical Overview

Ancients made "*terras mortars*" using *natron* (sodium carbonate), silt, and stone dust. This mixture "set" or hardened when mixed with water. It is known that natron was scooped from dry lake beds in Egypt. Gypsum mortars were also known in antiquity.

Romans used *pozzolanic mortar,* i.e. mortar made from calcerous clays that had been exposed to heat – either naturally (volcanic activity) or by man. They also developed lime based mortar for use when pozzolanic clay was unavailable. *Tabby mortars* were used in the coastal area until burnt lime became available.

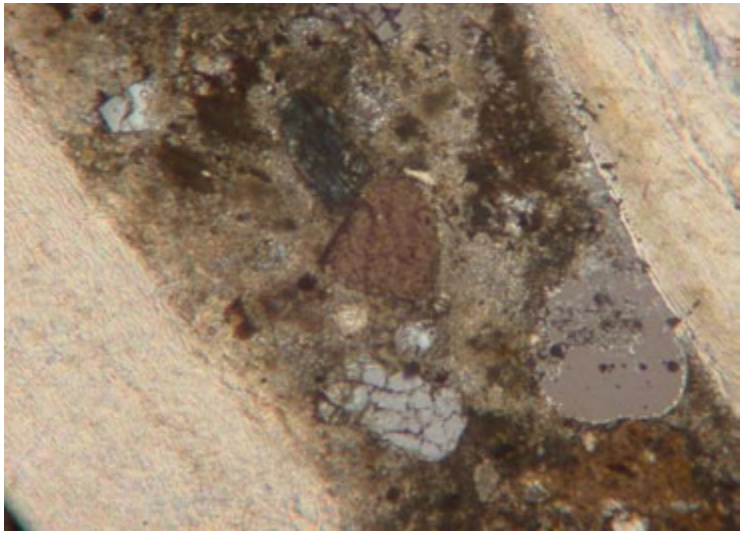
Lime based mortars were used, especially after the industrial revolution, until Portland cement was developed in the 1800's. Portland cement was not widely available in the United States until after the 1970's.

Limestone or sea shells ($CaCO_3$) are "burned" in a pit or a kiln, the latter sometimes called a "shaft kiln", to a temperature of at least 800^{o}C (1475^{o}F) to produce lime (CaO). The lime is mixed with sand and water to constitute the mortar. It "sets" on reaction with CO_2 in the atmosphere. *A good example of a colonial lime kiln can be seen at the Santee Canal Park*.

Tabby Mortar

Tabby mortar was used at the Dorchester Historic Site at the navigable headwaters of the Ashley River (town founded 1697). Records show transport of burnt shells (lime) and shells (as aggregate) upriver.

Tabby foundation with bricks and tabby mortar under door opening; Ruins of the Sams Plantation House (1786), Dataw Island, SC.



Stone masonry with lime based mortar (UK).

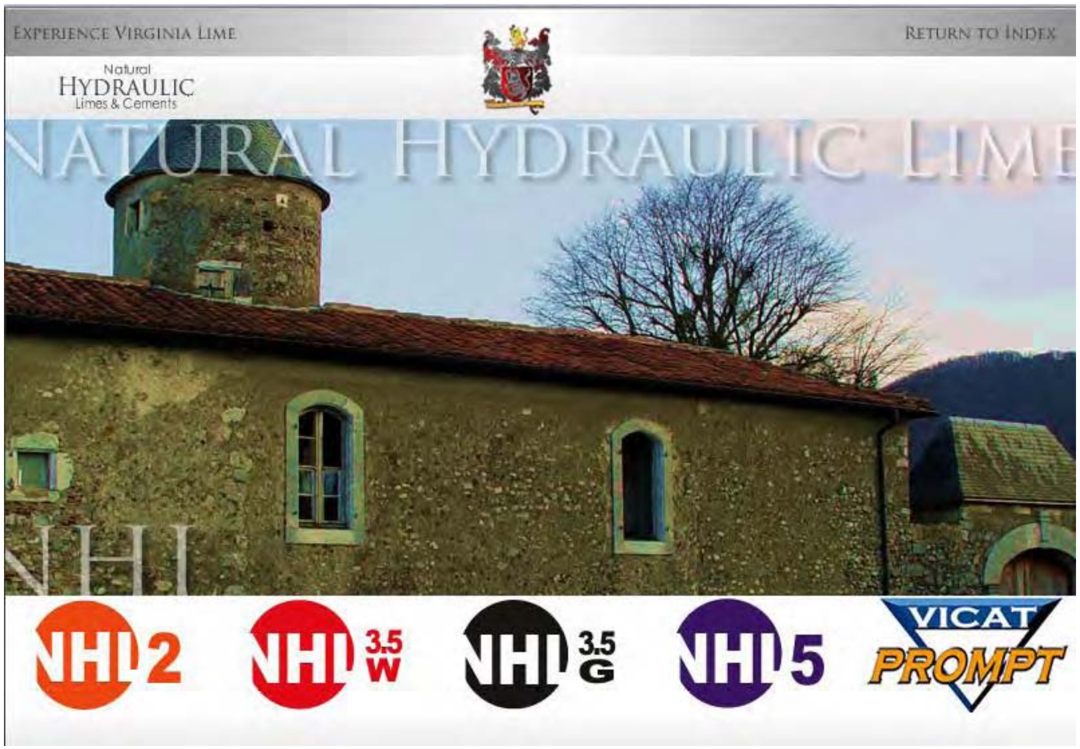
Lime putty – hydrated lime or $Ca(OH)_2$ formed by mixing burnt lime or CaO with water. The colonial practice was to store lime putty for a substantial period prior to use to ensure good hydration. The Romans stored it for five years prior to use.

Lime achieves a set condition by reacting with atmospheric carbon dioxide or CO2 forming a binder phase in mortar (binding sand particles and creating adhesion to masonry units) via:

$$Ca(OH)_2 + CO_2 = CaCO_3 + H_2O$$

This “recarbonation” is a slow process slowing down the pace of construction. Lime putty is available from the Virginia Lime Works in the USA.

Natural Hydraulic Lime – a product of burning *argillaceous* or *siliceous* limestone followed by slaking with or without grinding as may be necessary. They set by forming pozzolanic compounds as well as calcium carbonate.



The grades "2", "3.5", and "5" indicate the compressive strength developed in 28 days in Newtons/mm^2 (MPa). For reference, 2MPa, 3.5 MPa, and 5MPa correspond to 290 psi, 508 psi, and 725 psi respectively. This is much faster strength development than for lime putty mortars; yet it is "slow" by modern construction standards.

Natural Cement – Rosendale (Pre Civil War)

- 1817, natural cement rock discovered during the Erie Canal construction.
- 1824, Joseph Aspdin "invents" portland cement in the UK.
- 1825, natural cement rock discovered at Rosendale, NY. Rosendale becomes the dominant natural cement, although it was produced elsewhere.
- 1871, portland cement produced at scale in Coplay, PA.
- **1970, last or original Rosendale quarries closed.**
- 2004, Rosendale reintroduced by Edison Coatings.

Original Rosendale Kilns

Natural cement was based on the existing experience with HHL in Europe. The rock had a chemistry providing for pozzolanic reactions and hydration of belite (C_2S) – like NHL. The natural cement in the USA also contained a significant iron oxide content making it more resistant to salt attack than lime putty or NHL. It had a much higher hydration rate than lime putty or NHL (especially 3.0) allowing for faster construction.

Species	Natural MD	Natural NY*	Range for NY in References**	Contemporary Rosendale	OH PC
CaO	36.50	27.8	33-60	28.19	63.09
MgO	11.93		12-21	0.36	1.16
Al_2O_3	11.23	5.50	5.5-10	4.84	5.91
SiO_2	29.92	27.8	27-33	51.24	21.86
Fe_2O_3	4.78	4.3		0.28	2.45
TiO_2	--	--		0.14	--
K_2O	--	--		0.26	--
Total	94.36	94.32		85.31	94.47
CaO/SiO_2	1.22	1.28	>1.0	0.55	2.89

* Natural Cements – Analysis for Rosendale(Allan Rogers and Jerome Alexander, Industrial Chemistry, Edition 3, p. 304, 1920). ** W. Wahl, "On the Composition of Ancient Cements and Rosendale Cements", *Journal of the Franklin Institute*, pp.204-209 (1873).

Natural Cement in Georgia

Charles Wallace Howard, born in 1811, was a nineteenth century renaissance man: scholar, clergyman, writer, agronomist and geologist. He was a graduate of Franklin College and the Theological Seminary at Princeton, New Jersey.

In 1850, Reverend Howard founded the Howard Hydraulic Cement Company near Kingston. The quality of his natural cement had a national reputation and was used to build the East River Bridge in New York City, the Union Depot in Chattanooga, and buildings at Shorter College, to name only a few.

After the Civil War, Rev. Howard devoted his life to researching topics relevant to the economic growth of this area, writing many influential articles on minerals, coal, agriculture and livestock. Reverend Howard died in 1876 at his second home on Lookout Mountain. He is buried in the family cemetery at Spring Bank.

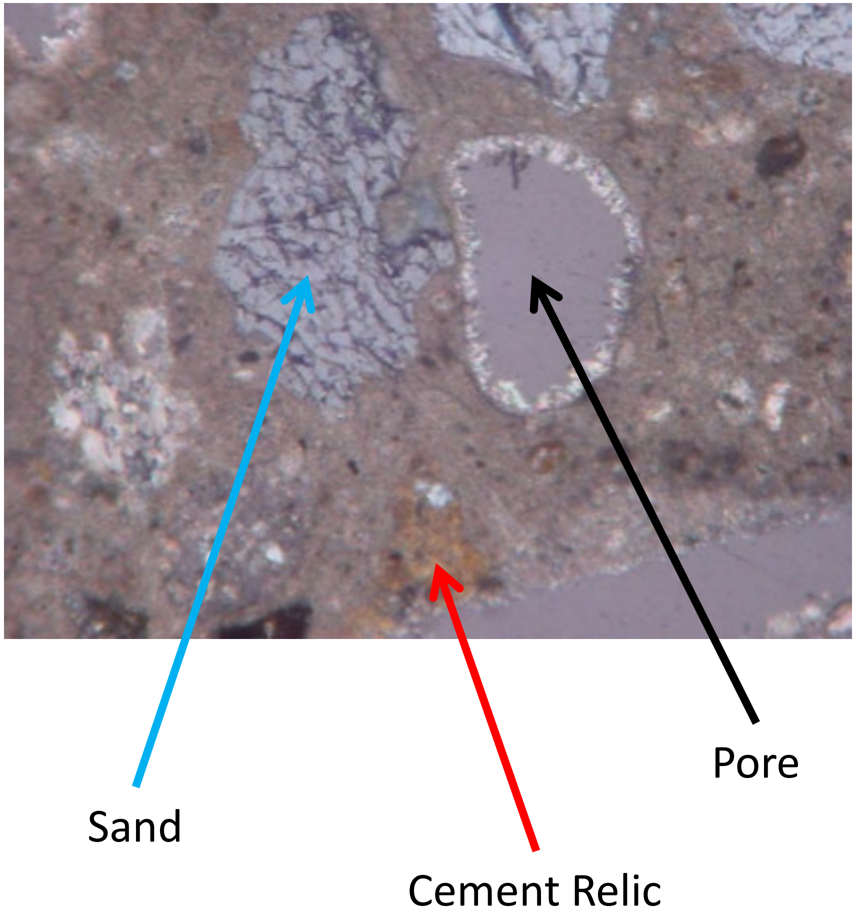
Species	Natural MD	Natural Rosendale	Range for NY in References	Howard Georgia	OH PC
CaO	36.50	27.8	33-60	48.18	63.09
MgO	11.93		12-21	15.00	1.16
Al_2O_3	11.23	5.50	5.5-10	3.35	5.91
SiO_2	29.92	27.8	27-33	22.58	21.86
Fe_2O_3	4.78	4.3		7.23	2.45
TiO_2	--	--			--
K_2O	--	--			--
Total	94.36	94.32		96.34	94.47
CaO/SiO_2	1.22	1.28	>1.0	2.13	2.89

Example: Ft. Sumter Material
Summary: Mortar, Sample 5

Left flank exterior sample C bedding mortar

Mortar Chemistry	
Al_2O_3	0.98
SiO_2	66.85
Fe_2O_3	3.49
TiO2	1.01
MgO	7.44
CaO	0.59
Na_2O	<0.5
K_2O	0.57
Sum of Major Constituents	88.11
LOI	11.55

Sand Chemistry	
Al_2O_3	<0.1
SiO_2	97.27
Fe_2O_3	0.71
TiO2	<0.02
MgO	0.60
CaO	0.69
Na_2O	<0.5
K_2O	0.11
Other MnO	0.01
P_2O_5	0.24
S	<0.05



Mortar Properties	
Bulk Density, g/cm3	1.32
Apparent Porosity, %	44.1
Percentage <1µ Pores	29.4

Portland cement (often referred to as **OPC**, from *Ordinary Portland Cement*) is the most common type of cement in general use around the world because it is a basic ingredient of concrete, mortar, stucco and most non-specialty grout. It is a fine powder produced by grinding Portland cement clinker (more than 90%), a limited amount of calcium sulfate (which controls the set time) and up to 5% minor constituents (as allowed by various[*which?*] standards).[*citation needed*]

As defined by the European Standard EN197.1:

Portland cement clinker is a hydraulic material which shall consist of at least two-thirds by mass of calcium silicates alite and belite ($3CaO.SiO_2$ and $2CaO.SiO_2$ respectively), the remainder consisting of aluminum- and iron-containing clinker phases and other compounds. The ratio of CaO to SiO_2 shall not be less than 2.0. The magnesium content (MgO) shall not exceed 5.0% by mass.[*cite this quote*]
(The last two requirements were already set out in the German Standard, issued in 1909).[*citation needed*]

Portland cement clinker is made by heating, in a kiln, a homogeneous mixture of raw materials to a sintering temperature, which is about 1450 °C for modern cements. The aluminum oxide and iron oxide are present as a flux and contribute little to the strength. For special cements, such as Low Heat (LH) and Sulfate Resistant (SR) types, it is necessary to limit the amount of tricalcium aluminate ($3CaO.Al_2O_3$) formed. The major raw material for the clinker-making is usually limestone ($CaCO_3$) mixed with a second material containing clay as source of alumino-silicate.

Normally, an impure limestone which contains clay or SiO_2 is used. The $CaCO_3$ content of these limestones can be as low as 80%. Second raw materials (materials in the raw mix other than limestone) depend on the purity of the limestone. Some of the second raw materials used are: clay, shale, sand, iron ore, bauxite, fly ash and slag. When a cement kiln is fired by coal, the ash of the coal acts as a secondary raw material.[*citation needed*]

Wikipedia

Two factors have facilitated use of modern Portland Cement in construction:
(1) The widespread availability of limestone for its production and (2) the rapid setting of the material to speed construction.
In 28 days, Portland cement based mortars reach at least 60% of their ultimate strength.

OPC Mortars are Mixtures of Cement, Sand, and Lime

Quick Generalities about OPC mortars

- Strength increases as the cement content increases.
- The Modulus of Elasticity (rigidity) increases as the cement content increases.
- The workability of the mortar increases as the lime content increases.
- The mason is a "technique sensitive" human being – *only dentists are more extreme*.

Type	Parts Cement	Parts Lime	Parts Sand	28-day Strength, psi (N/mm^2)	Use
M	1	¼	3	4800-5400 (33-37)	General use; foundations, sidewalks, in contact with ground.
S	1	½	4.5	2100-2800 (14-19)	Resistance to lateral shear.
N	1	1	6	800-1200 (5.5-8)	General use severe exposure above grade.
O	1	2	9	<1000 (<7)	Low strength load bearing walls.

For comparison, 28-day strength of NHL mortars is about 0.3 N/mm^2 (3.0), 1.0 N/mm^2 (3.5), and 3.0 N/mm^2 (5.0).

Engineered Restoration Mortar – Jahn

See http://www.cathedralstone.com/

Jahn Facts:

- Developed in the Netherlands.
- Favored on continental Europe (but NOT in the UK).
- An outgrowth of "Dutch "Glue Mortar" (a finer particle size pumpable mortar product).
- Contains portland cement and substances to encourage pozzolanic reactions, i.e. possibly fly ash/fumed silica.
- 28 day strength of 3000-3800 psi (21-26 N/mm^2).
- Porosity can be varied in the range 4% - 16% to deal with vapor permeability.

JAHN M100

- **Terra Cotta Repair**
- **Brick Repair Mortar**

CERTIFIED INSTALLERS ONLY

This single-component, cementitious, mineral based mortar is designed for the restoration of terra cotta and brick surfaces. **Jahn M100 is completely vapor permeable and contains no latex or acrylic bonding agents or additives.** M100 is specifically engineered for compatibility with oven-fired materials to provide a permanent repair, which both enhances and protects the original substrate. (Only Certified Installers may purchase Jahn M100 Terra Cotta Repair Mortar.)

To restore the original glaze and keep water from entering the substrate through the new repair, use **TerraCoat Glaze Repair** to paint the repair. (Call Cathedral Stone at 800-684-0901 for more information about our complete line of TerraCoat Glaze Repair products.)

Features and Benefits

- **Single-Component:** Mixes with water only, improving quality control and consistency of application.
- **Compatibile Formulations:** Compatibility of physical properties ensures that the mortar and natural substrate react to the environment in the same way.
- **Contains No Latex or Acrylic Bonding Agents:** It protects the substrate by allowing salts, water vapor, and liquid water to reach the surface, preventing failure due to salt expansion or freeze/thaw cycles.
- **Tenacious Adhesion:** Strong bonding capabilities without relying on synthetic bonding agents.
- **Factory Controlled:** No field chemistry resulting in product variation.
- **Custom Colored Upon Request:** Closely matches existing masonry. Choose from Standard or Custom Colors.

Application Procedures

Surface Preparation

Surfaces to receive M100 must be sound and free of all dust, dirt, grease, laitance and/or any other coating or foreign substance which may prevent proper adhesion. Remove all loose and deteriorated masonry from the repair area using manual or pneumatic cutting tools. Areas to be repaired should be cut to provide a minimum of ½" depth. Do not install repairs that have a feathered edge (see diagram below), incorrect installation will cause repairs to fail prematurely. Wash the prepared surface with clean water and a bristle brush to remove dust from the pores.

Section: Correct *(Square Cut)* Surface Preparation

Section: Incorrect *(Feathered Edge)* Surface Preparation

Mixing

The mixing ratio is approximately 4 ½ to 5 parts powder to 1 part water by volume, **depending on temperature and humidity.** More water may be required as ambient temperature rises. The mixing may be done by hand, stirring until the mortar is thoroughly mixed. The mortar should be the consistency of stiff putty, without lumps. M100 may also be mixed using a slow speed drill (400 - 600 rpm) equipped with a Jiffler-type mixing paddle. For best results, add the powder to the water slowly. The working time will vary, depending upon wind, temperature, and humidity. Using excessive water in the mixture may affect the color of the repair.

Application

Moisten the substrate using clean water. Jahn Mortar should be applied to a glistening wet surface on vertical applications and a well-dampened surface (with no pooling water) on horizontal applications. **If the surface is allowed to dry out before applying M100, this step must be repeated. This is very important.**

The next step of the application is what CSP has termed the "Peanut Butter" coat. The Jahn mortar should be mixed with water to the consistency of wet putty. Apply the "Peanut Butter" coat to the glistening wet substrate approximately 1/8

Cathedral Stone® Products, Inc. 7266 Park Circle Drive, Hanover Maryland 21076
(800) 684-0901 FAX: (410) 782-9155 WEBSITE: www.cathedralstone.com

*"**Masonry cement** - a **hydraulic cement**, primarily used in masonry and plastering construction, consisting of a mixture of **portland or blended hydraulic cement** and **plasticizing materials (such as limestone, hydrated, or hydraulic lime)** together with **other materials** introduced to enhance one or more properties such as setting time, workability, water retention, and durability*." ASTM C91-05.

GLOSSARY

Hydraulic cement – substances that chemically react with water to form a solid mass. The reaction is influenced by temperature and pH of the water.

Portland cement – forms compounds of lime, silica, and water on setting.

Blended cement – **"other"** hydraulically setting phases with portland cement.

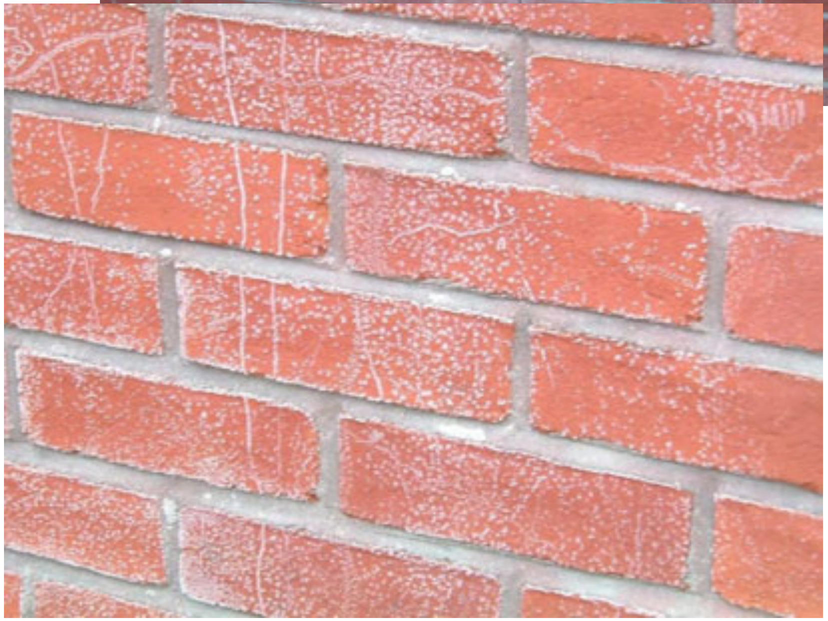
These "other" phases might be by-products of portland cement production.

Plasticizers – limestone, lime, and other minerals – some partially soluble.

Other materials – primarily substances that provide air entrainment.

About Efflorescence

- Efflorescence is a discoloration due to the deposition of soluble salts on the surface of a masonry wall during a “drying period”.
- Wetting is essential for efflorescence to develop – more water is usually linked to more efflorescence.



USE CARE! I do not recommend use of masonry cements or mortar cements in ANY historic preservation and restoration effort without careful laboratory evaluation of its efflorescence potential.

Properties of Field Produced and Cured Historic Mortar

Mortar	Bulk Density g/cm^3	Apparent Porosity, %	% Pores <1μ
Rosendale 1:3:3 (#9)	1.72	30.0	80.4
OPC 2:1:6 (#5)	1.95	19.8	84.0
Jahn (#10)	1.59	34.5	94.0

Modern Mortar (cement/lime/sand)

Type M: 1:¼ :3
Type S: 1:½:4.5
Type N: 1:1:6
Type O: 1:2:9

Implied Vapor Permeance

Mosquera, et. al., report vapor permeance of mortars of similar porosity and similar fraction of pores <1μ to be in the range of 3-5.4 (X10^{-6} m^2/s). The fraction of pores less than one micron influenced vapor permeability in a more significant amount than quantity of porosity. Mosquera found lime putty to be 5-6 times more permeable than cementitious mortar or NHL. (See "Addition of cement to lime based mortars: effect of pore structure on water transport", Cement and Concrete Research 36 (2006) 1635-1642.

The results imply similar vapor permeabilities when comparing modern Rosendale mortars with OPC based mortars. Since hand molded bricks have much larger pores than the mortars, the high attention to vapor permeance may not be *always* justified.

Material	Compressive Strength, psi	MOE, ksi
Ft. Sumter Bricks	1235-1440	508-1160
OPC mortars*	1865 @ 7 days 1:1 cement/sand	1923-3571
Natural cement mortars*	85-210 @ 7 days	1667-2500
Rosendale mortars**	1020 @28 days (1:1 cement/sand)	535-640
Jahn mortars (M110)	370 and higher (Type O)	105-155

*Cement and Concrete by L.C. Saban (1907); Ft. Sumter brick data by Brosnan; Other data from manufacturer.

Comparison of Mortar Strength and Rigidity

Any mortar *containing lime* is likely to be weaker and less rigid than the existing Charleston Grey bricks on Ft. Sumter. Pointing mortar, HOWEVER, based on OPC and sand can be stronger and more rigid than the bricks.

Reasons Not to Love PORTLAND

- It’s not historically original!
  (But is today’s Rosendale authentic?)
- It is too rigid - high Modulus of Elasticity!
  (But the same may be true for historic Rosendale).
- It is not permeable to water vapor!
  (But all mortars are permeable to water vapor).
- Rosendale is a natural cement – like Roman cement!
  (But portland cement is based on a similar chemistry idea – cement hydrates in the lime-alumina-silica chemical “system” provide strength.)

Masonry Assemblies

Wood Frame Structure with Brick Veneer.
Technically: Drainage Wall Construction

Load Bearing Wall Sheldon Church
Technically: Barrier Wall Construction

Tests For Brick Assemblies

Flexural Strength, E 518 and C 1072

Water Penetration, E 514

Freezing and Thawing Resistance
(British Panel Test)

Fire Resistance

Shear Strength, E 518 (In-Plane)

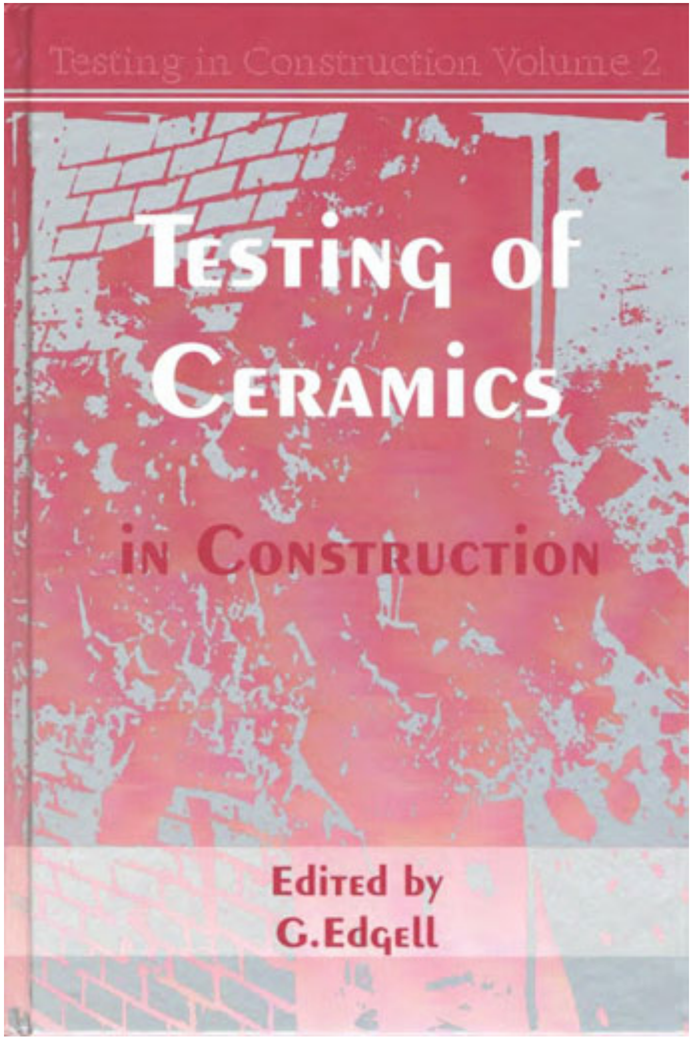
Strength and Deformation (Out-of-plane)

Modulus of Elasticity

Heat Storage and Transmission

Pull Out/Penetration/Impact Tests (Fixtures)

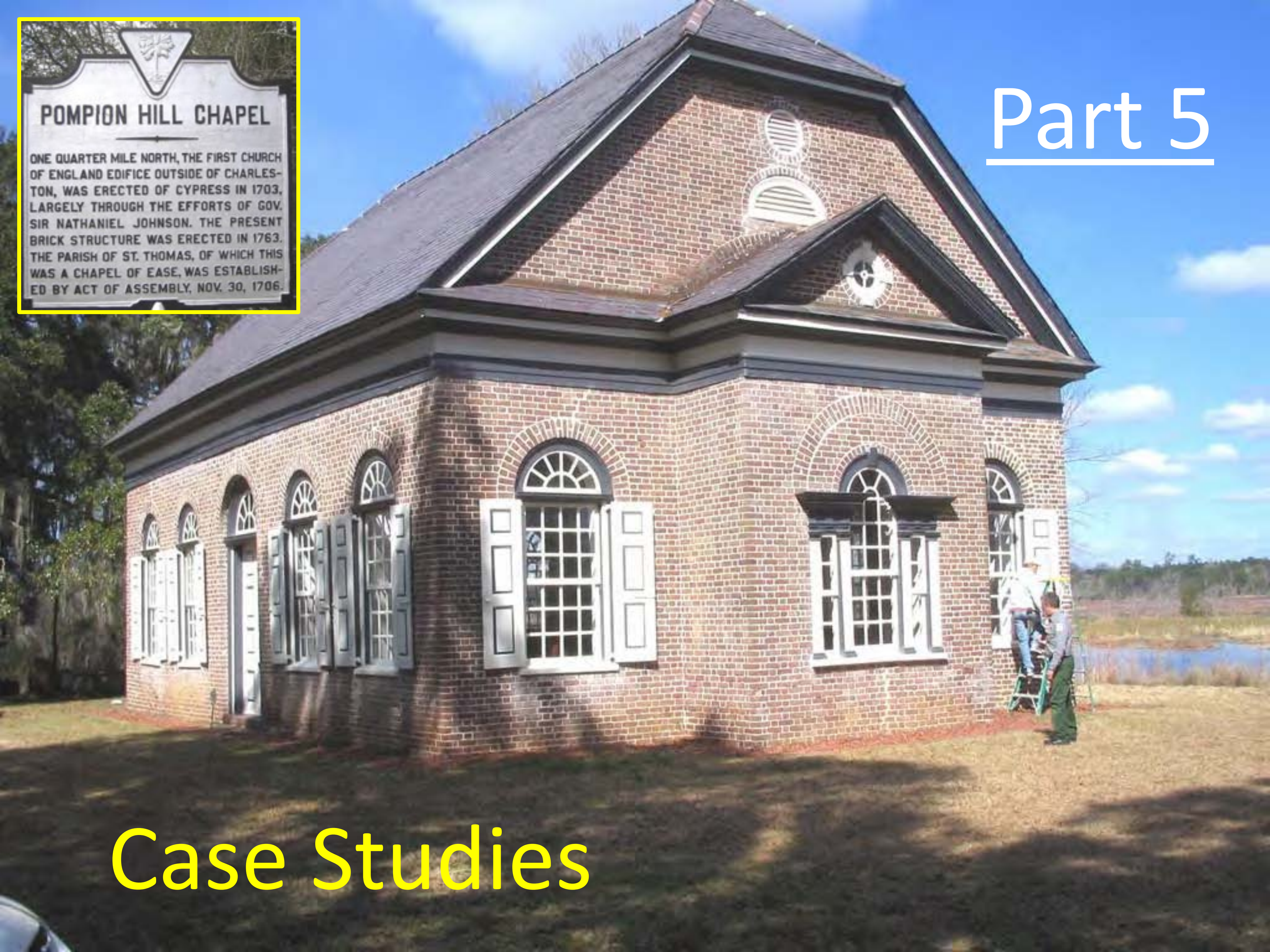
Creep



Whittles Publishing, ISBN 1-870325-43-5 (2005)

Questions on Part 4?

Part 5



Case Studies

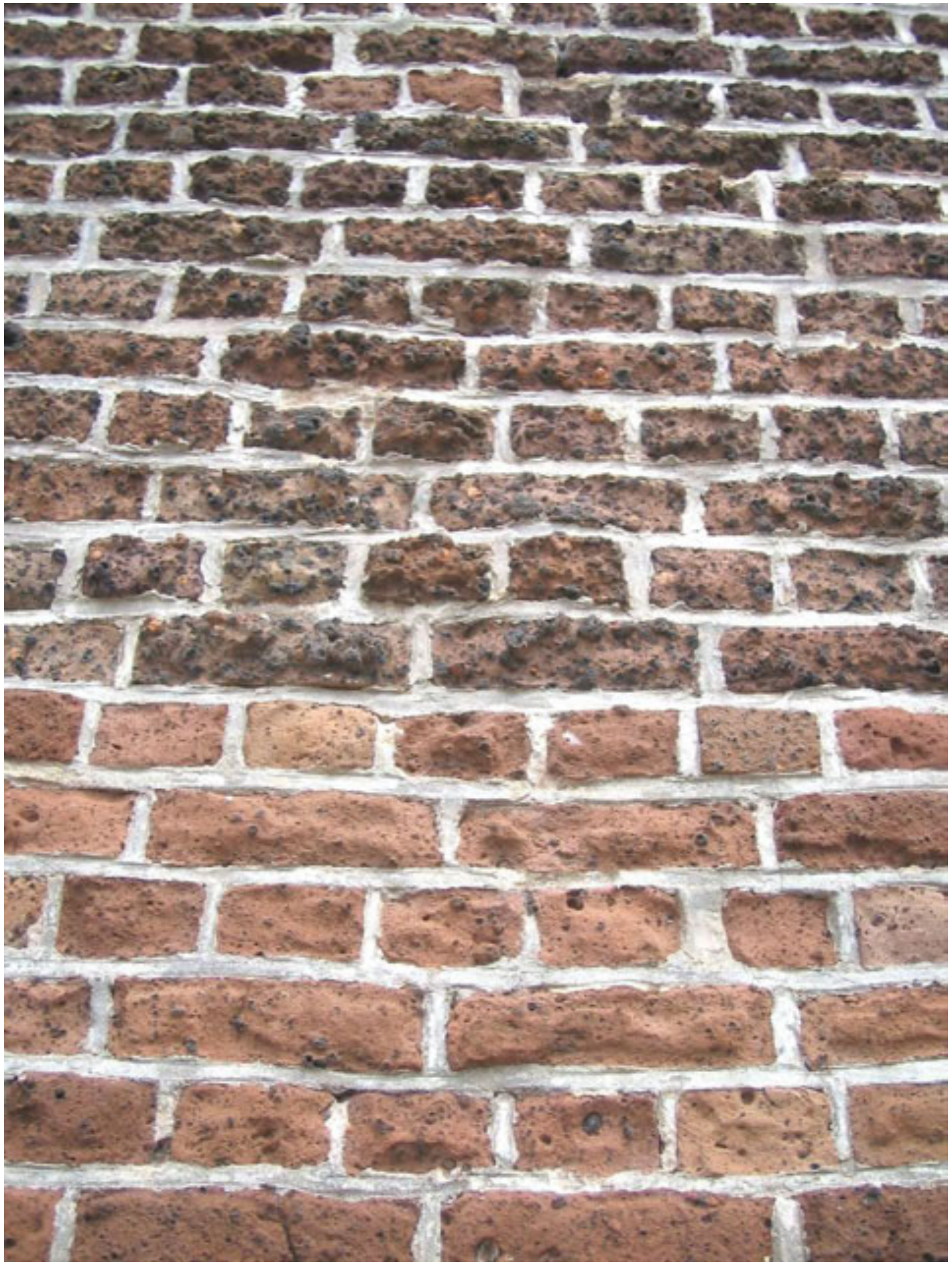
Water

Rising Damp

The solubility of calcium carbonate in water is 0.0014 grams in 100 cubic centimeters. This is sufficient for the long-term destruction of the carbonate phase in lime based mortars. Salts from ground water or sea water exacerbate the solution of the lime. This is frequently seen when there is pooling of water in a foundation.

Fire

Calcium carbonate decomposes before 1775^{o}F. Modern engineers think this destroys the mortar joint. What they don't know is that the mortar will "re-carbonate" *given enough time*. It was common practice prior to WWII to re-use the load bearing shell of a building after a fire.



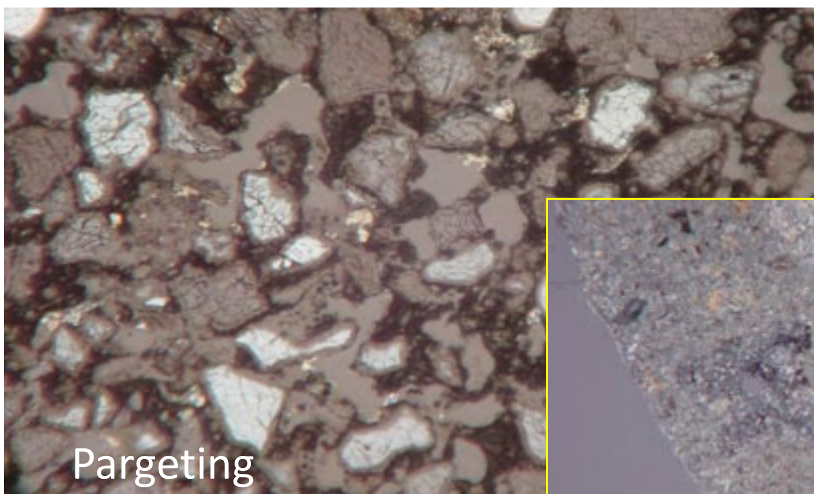
Left Face of Ft. Sumter National Monument

Wind

Over 150 years of exposure to airborne sand particles created a “sandblasted” look to the face of Ft. Sumter. Hard “chert nodules” (black) stand out from the softer vitrified continuum in the bricks. Paving brick standards reference a “sandblasting” test for bricks (C 418), but there is no data for bricks in the technical literature.

Salt Water (Mortar)

SOLUBLE SALTS	Quantity (ppm of solid)
Na	2066
K	254
Mg	75.4
Ca	1807
PO_4	---
Cl	5801
NO_3	12.3
SO_9	824
F	57.2
Br	19.3
Pore Data	
Bulk Density, g/cm3	1.73
Apparent Porosity, %	24.3
Porosity %, <1µ	74.7



Salt laden water has removed the carbonate phase (now seen as “black holes”).

Lubelli, et. al, On The Role of Sea Salt in Mortar and Brick Deterioration

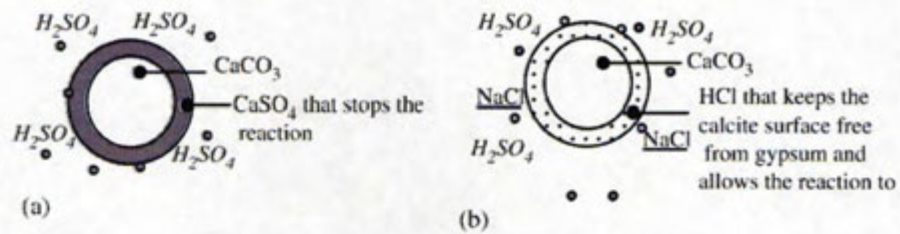


Fig. 6. $CaCO_3$–H_2SO_4 reaction leading to gypsum in absence (a) and in presence (b) of NaCl.

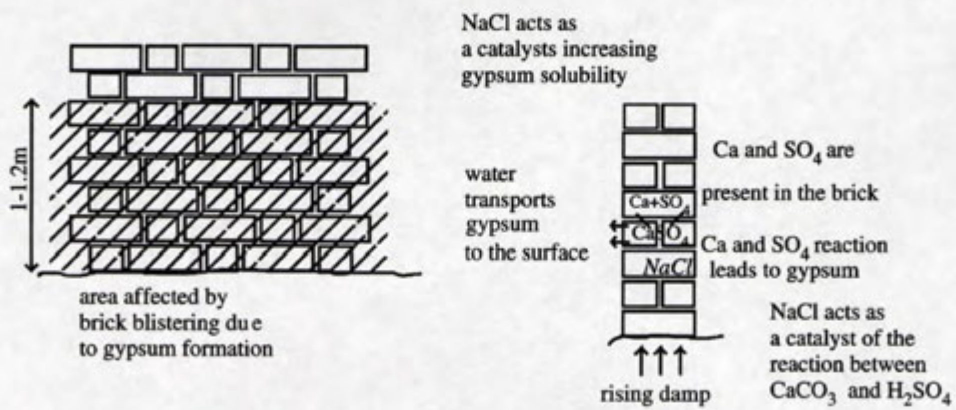
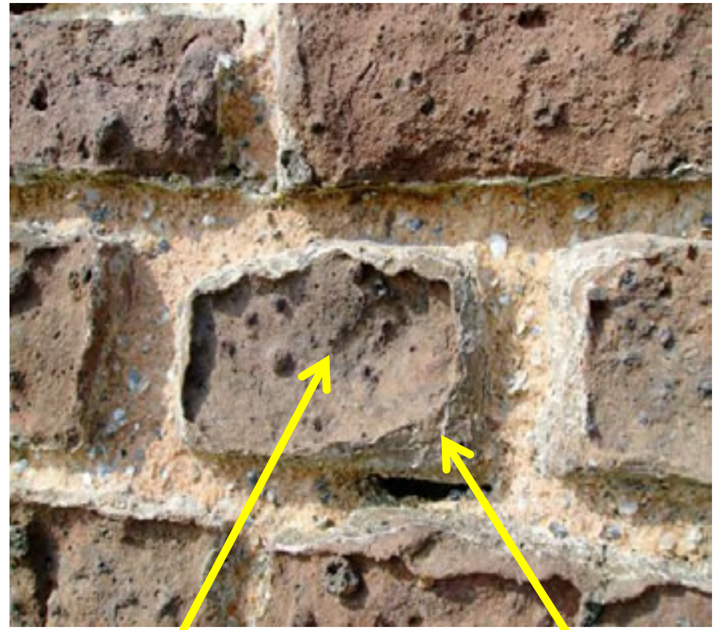


Fig. 7. Hypothesis on the mechanism of brick blistering.

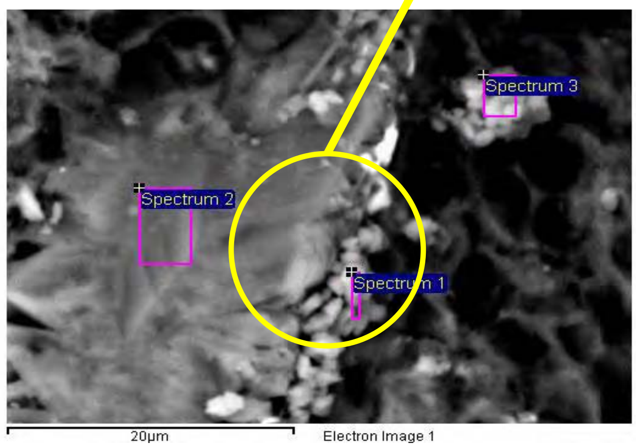
The key observation is that the CALCIUM in masonry comes from the mortar. Therefore, mortar more resistant to salt attack preserves both the mortar and the brick.

Cryptoflorescence Failure - Bricks

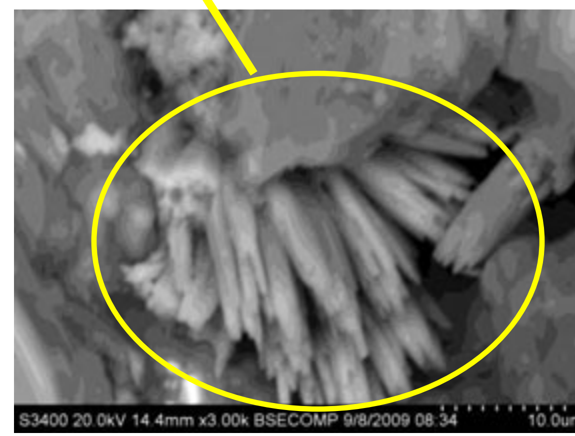
This type of failure illustrates the role of pointing mortar in failures. The dissolved calcium has precipitated in cracks on the edge of the brick formed by cryptoflorescence and mechanical processes. The face of the brick bows outward and pops off. It is also called “scaling”.



The presence of ettringite suggests subsurface expansion that can damage the bricks.



Cubic salts in center (Ca Present)

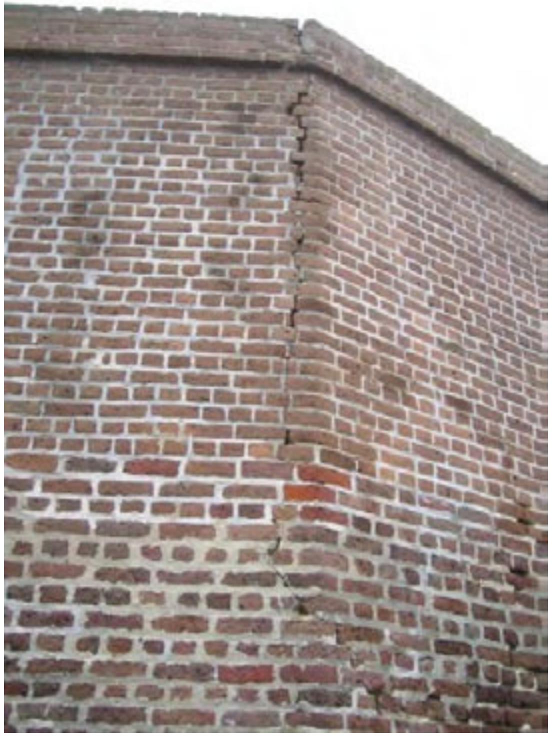


Ettringite near edge in brick. (calcium sulfoaluminate)

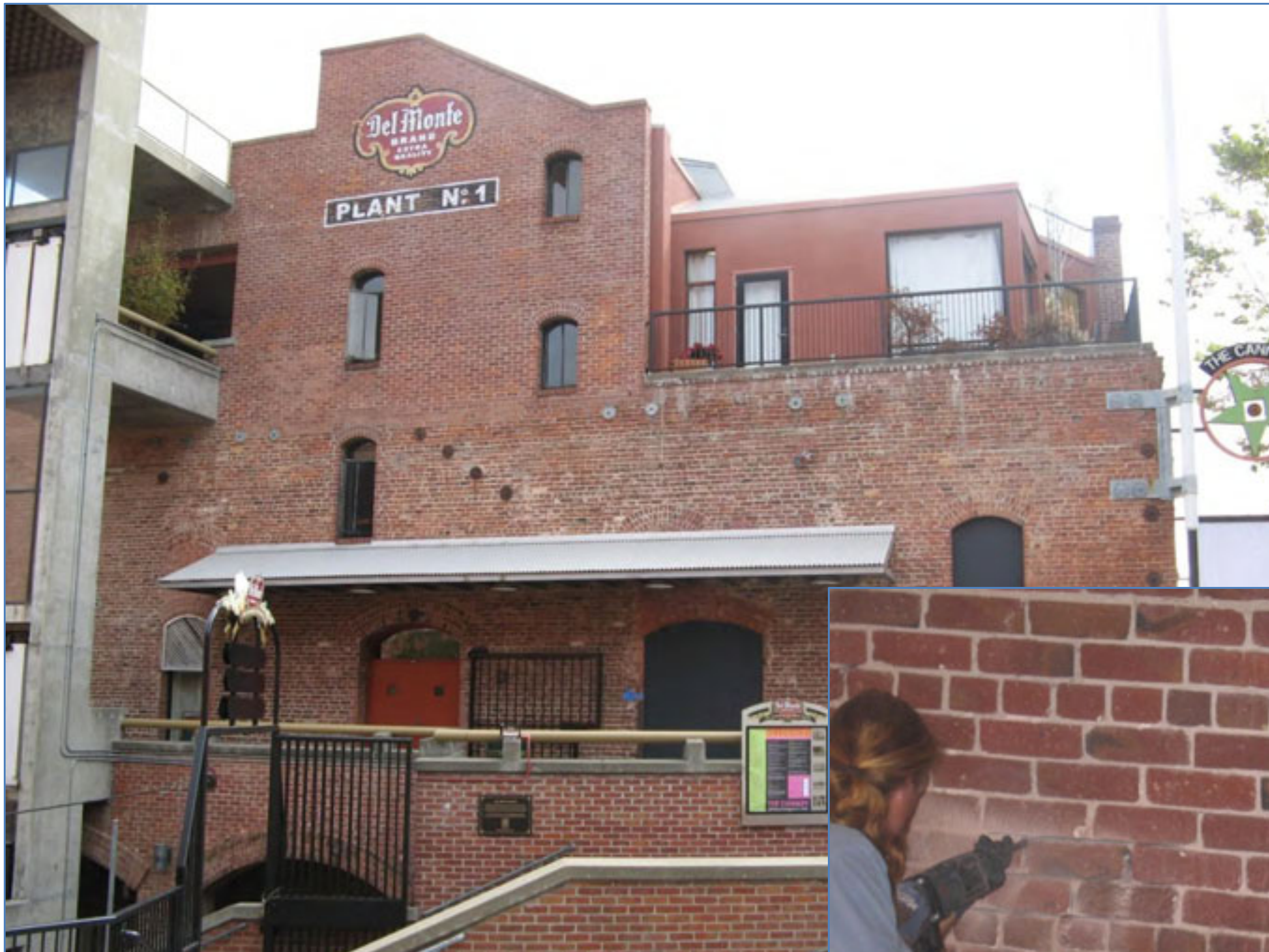
Movements; Imposed Stress

It is fairly common to see cracks in the mortar joint where foundation subsidence provides a "familiar" stepwise crack up the masonry (below).

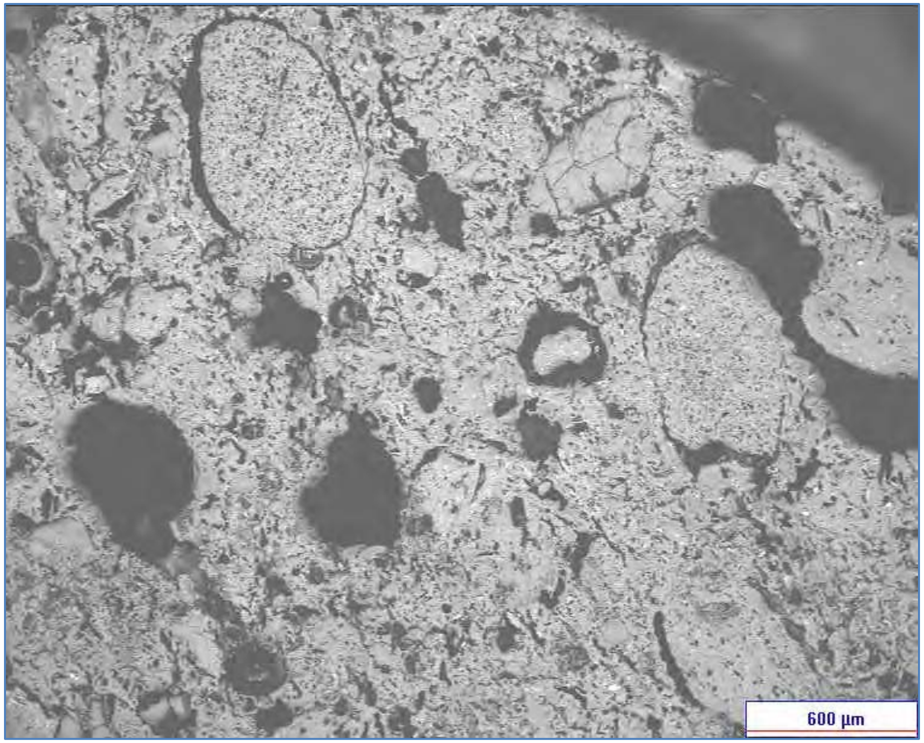
On a corner, forces where walls meet may cause fractures through bricks suggesting movements were caused, in part, by thermal expansion of the walls.



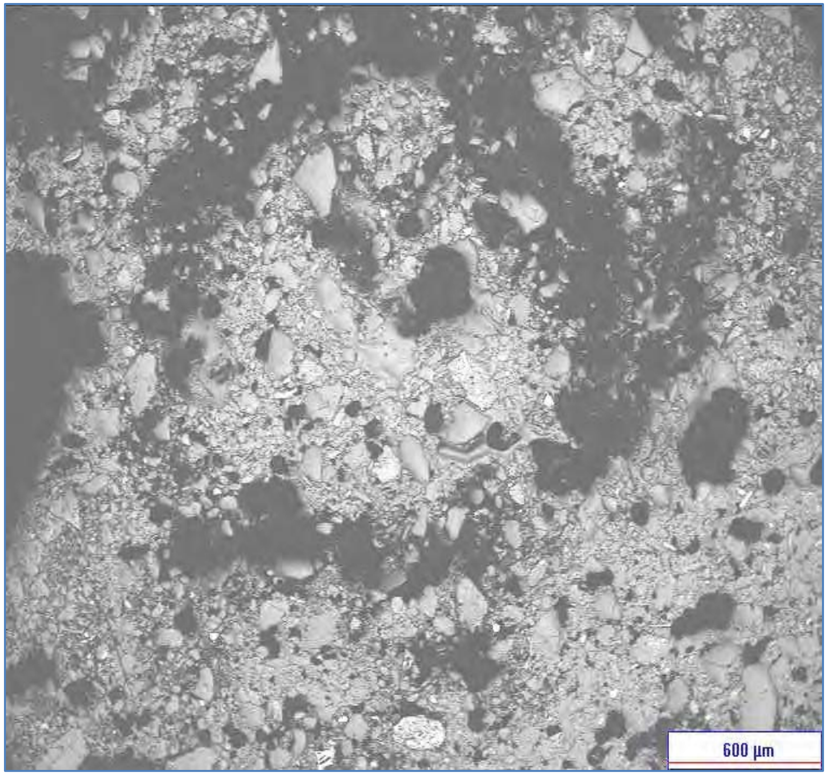
Dissimilar Materials (Different Modulus of Elasticity)



The Cannery, San Francisco (1907)
Replacement Bricks at High Elevation



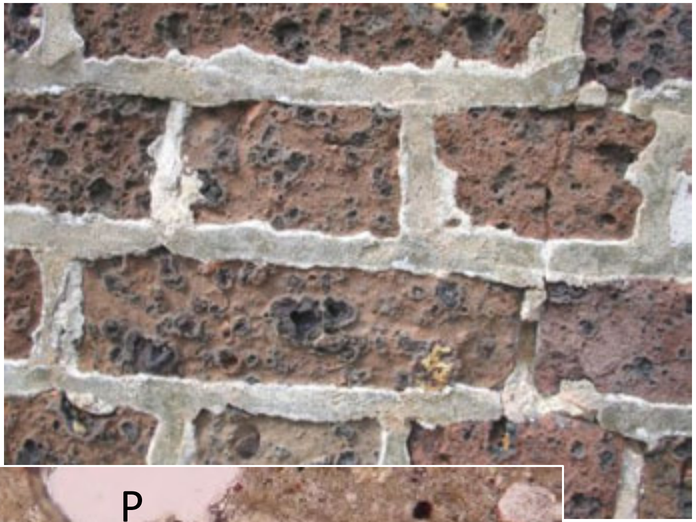
← The 1907 brick was hand molded, and contains come mineral phases only attributable to the San Francisco area.



The 1967 replacement bricks were hand molded and did not meet ASTM C 216 SW property values suggesting they were of Mexican origin. →

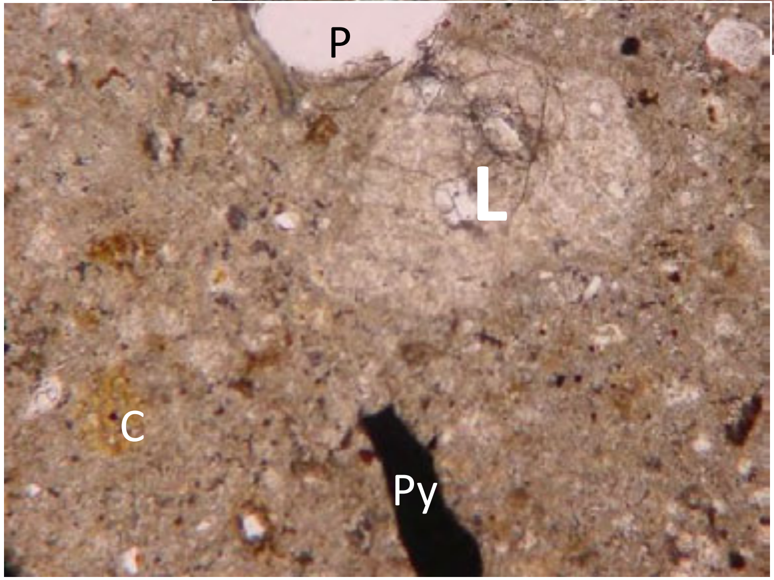
Did the restoration architect choose authenticity over engineering common sense?

Pointing – periodic replacement of surface mortar is required to maintain effective barriers to the elements. Pointing mortars are lightly “sanded” to form a smooth surface.



An “original” pointing mortar at Ft. Sumter national Monument contained Rosendale cement , lime, and sand in volumetric proportions:

1 (cement) : 1 (lime) : 0.5 (sand)

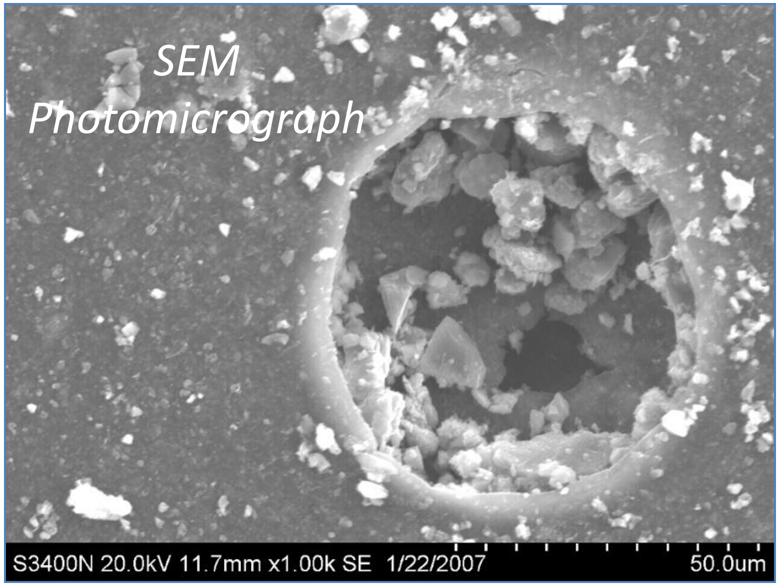


P = pore; L = lime agglomerate; C = cement agglomerate, Py = pyrite.

Coating Historic Bricks

Searls Hall, Bowdoin College, ME Built (1844-55)

What Caused the Salt Staining on Searls Hall?



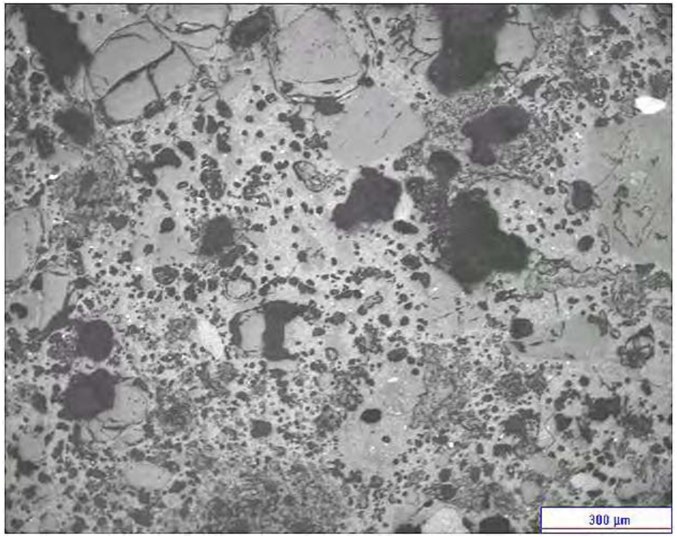
"Pinhole" in Coating With Salt Crystals Visible

Constituent	Specimen B3
Al_2O_3	25.61
SiO_2	55.75
Na_2O	3.00
K_2O	2.20
Fe_2O_3	5.85
MgO	3.65
CaO	**2.85**

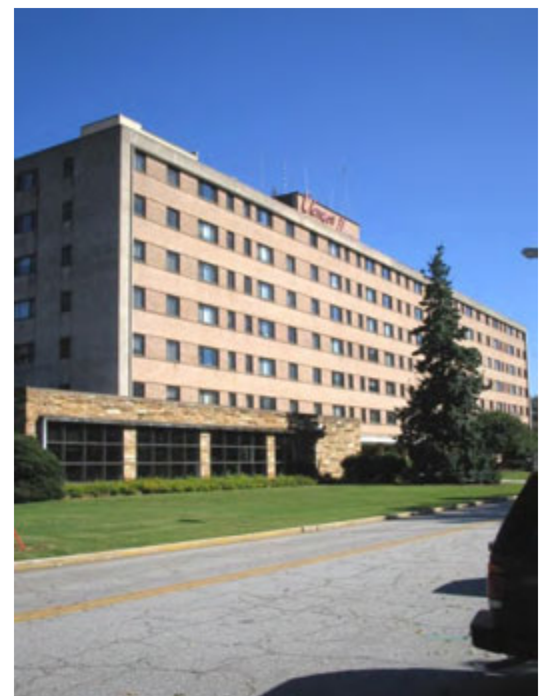
The investigation found:

- The building was painted in the 1950's because of its light color.
- Limestone and ash relics in the brick composition contributing to soluble calcium within the bricks.
- 13.8% CaO on the brick surface (<3% in the bricks).
- 8861 ppm of soluble sulfate (SO_4) in the Searls Hall mortar.
- The salt deposit is comprised primarily of calcite or $CaCO_3$.

Can you Insulate Load Bearing Walls in a Building from the 1800's?



Will Face Cracks Cause My Building to Fall Down?

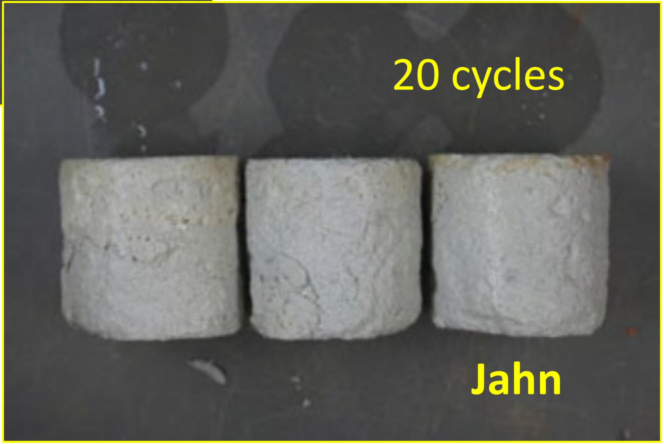


Authenticity Versus Engineering

Beaverdam Baptist Church
Mountville, SC
(Built before the Civil War up to eves; Finished after the Civil War). Did the kiln fireman survive the war?

Mortar Performance Tests: Immersion Cycles with Expansion and Soluble Salt Measurements - 2009

- Specimens field fabricated, cured 7 days @ 70F at 100% RH, also cured 7 days at 70F in 100% CO_2.
- Best performers in sea water immersions for Ca removal: Rosendale mixes and Jahn
- Low expansion: Rosendale and Jahn equivalent.
- Performance in Sodium Sulfate: Rosendale and OPC similar. Jahn best!
- Lime putty intermediate in Ca leaching but high expansion.
- Worst Performer in Sea Water: NHL



Questions on Part 5?

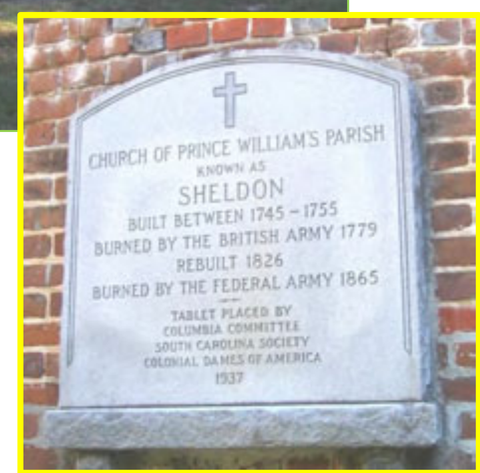
A Little Review on "Greenness" and South Carolina Brick Masonry

- Brick masonry is GREEN because of its proven longevity. Fired bricks date back to 5000 BC. Brick masonry from the colonial period in America survives!

- Bricks were made by societies because of their durability and fire resistance.

- Brick masonry needs periodic maintenance, and "best practices" need to be logically developed for historic buildings.

- A new generation of architects is focused on sustainability. This is driving us to build "green" institutional structures. Our society needs to find ways to make green residential buildings affordable.




A Little South Carolina Mystery
Why three different bricks in the firebox?