Guide for Replacement Bricks in Restoration of Masonry in Historic Buildings

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THE PURPOSE OF THIS GUIDE IS TO AID in the restoration of historic buildings in North America by listing criteria for brick selection. Another purpose of this article is to present pictures of historic and modern bricks so that people involved in restoration can recognize the way that bricks were produced by their facial characteristics. The production method for bricks may be useful in choosing replacements.

These criteria should be considered by people who guide restoration efforts and for brick manufacturers who supply the clay masonry units. Substantial research has been conducted in Europe on this selection of bricks for restoration, and resources are readily available in literature. Considering the European progress in restoration, it is important to recognize that raw materials for brick production in North America were somewhat different than those available in Europe – particularly along the coastal zones, and brickmaking technology in North America lagged until after the American Civil War (1865). Therefore, the era when a building was produced and its location can influence criteria for brick selection.

This guide neither addresses diagnosis of masonry problems nor safety of the structure for restoration efforts. It is always mandatory that an assessment of the structure by qualified personnel, including structural engineers, is conducted prior to removal of original materials for laboratory study or prior to making repairs. References are provided at the end of this article that can be used to guide diagnostics and safety assessments. Safety assessments necessarily involve considerations on foundations of garden walls and other free standing masonry.

Because brick were part of a masonry system, the characteristics of the mortar involved in the original construction are of paramount importance. Fortunately, ASTM C1713 entitled *Standard Specification for Mortars for the Repair of Historic Masonry* is of essential value with historic buildings. ASTM also has C1722, *Standard Guide for Repair and Restoration of Dimension Stone*. Other assistance is found in the National Park Service's *Preservation Briefs*, where *Preservation Brief 2* is entitled "Repointing Mortar Joints in Historic Masonry Buildings."

2010 Restoration of Pompion Hill Chapel, Upper Santee, SC (Structure Erected 1763)

Detail of Handmade Bricks, Pompion Hill Chapel after Pointing

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Machine Molded Bricks with Raked Mortar Joint (Clemson House, Clemson University, 1950)

The First Criterion for Replacement Bricks

The Secretary of the Interior (USA) published Standards for the Treatment of Historic Properties in 1995 (www.cr.nps.gov/local-law/arch_stnds_8_2htm) that state:

"Work needed to stabilize, consolidate, and conserve existing historic materials and features will be *physically and visually compatible*, identifiable upon close inspection, and properly documented for future research."

This clearly places *aesthetics* in the forefront of any restoration effort. This means the following:

1. The *color* of replacement bricks will match the color of the original bricks in the structure and be compatible with the *color range* of bricks in the existing masonry. The color range of bricks in historic buildings was particularly affected by fuel type and location in kilns presenting "flashed" ranges of color. For many buildings, the color of the original bricks should be determined after cleaning of the masonry using procedures suggested by cleaning professionals. Care must be taken to avoid color burn (color alteration by acids) and other problems by using test areas away from direct sight lines for cleaning. ASTM D5703, *Standard Practice for Preparatory Surface Cleaning for Clay Brick Masonry*, or *Preservation Brief 1 - Assessing Cleaning and Water-Repellent Treatments for Historic Masonry Buildings* are useful resources. Scolforo and Browne state that some brickwork may not require cleaning or that cleaning may not be a part of some restoration projects (See references).

2. The *physical dimensions* or size of bricks should match those in the original structure.

3. The *surface features* of brick should closely resemble those on bricks in the original structure. Per ASTM C1232, *Standard Terminology of Masonry*, "surface features include coatings, colors, textures, relief, or combinations of these." Surface features are typically unique to a manufacturing method per the table below. In recent years, extruded bricks with many apparent surface features of molded bricks have been produced through applications of thick coatings (called "engobes"), thin coatings, colorants and sands.

4. The color and size of mortar joints used in repair must match that of joints in the historic building.

Modern Handmade Bricks

Characteristics of Historic Bricks by Forming Method			
Manufacturing Method	**Dimensional Precision**	**Usual Characteristics**	**Comment**
Hand Molded	Low	Folds of clay visible on surface, rounded corners. May be sand coated (sand struck) or smooth (water struck).	Most brick made in North America prior to about 1850. Still available from some manufacturers.
Machine Molded	Low	Rounded corners, possible non-prismatic shape, frogged (depression in) face possibly with a brand marking, other face with typical look of "smeared clay." May be sand coated (sand struck) or smooth (water struck).	Introduced in North America with advents of steam power and later electricity. Still produced in locations like the North Eastern United States.
Pressed	Very High	Uniform in shape and physical dimensions.	The peak production of pressed bricks was in the early 1900's. Currently available from only a limited number of manufacturers. Contact the Brick Industry Association for availability.
End Extruded	Medium	May contain striations/scratches along faces parallel to the long dimension of the brick.	Production ceased prior to about 1960.
Extruded	Medium to High	Can exhibit no coring/perforations or can typically exhibit 3 or 10 holes on a bedding face. Can exhibit coatings or engobes to create color and texture. Some brick may be "tumbled" to round corners.	Introduced in North America with advents of steam power and later electricity. Improvements in density (and reduction in absorptions) were attained through vacuum extrusion (after about 1950). Stiff extrusion is employed in the USA and Canada (while soft extrusion may be used in other parts of the world).

Use of Reclaimed/Salvaged or Historic Bricks

Scolforo and Browne state, "There are important reasons why salvaged brick are not recommended as replacement brick."(See references). The main issue revolves around the *unknown durability* of reclaimed bricks. For example, most buildings prior to World War II were designed with multiple wythes (layers) of bricks constituting a load bearing wall, with durable facing bricks on the exterior and structural bricks or "common bricks" on the interior. The common bricks were usually produced simultaneously with the facing bricks, with the facing bricks so graded by color and or "ring." It is also true that dark colored deformed bricks or those containing cracks were "downgraded" as common bricks. The key issue is that the durability of such common/structural bricks is *unknown*, and their durability can only be estimated by experts using analytical tests. For this reason, the Brick Industry Association has always not recommended the use of reclaimed bricks in *Technical Note 15* (the basis for Scolforo and Browne's comments).

It is further important to ignore uninformed opinions on restoration. One reference states, *"If the exterior surfaces of the brick are severely deteriorated, it is sometimes possible to reverse the bricks if their interior faces are capable of withstanding atmospheric conditions."* With one face severely deteriorated, how can you justify turning the brick around expecting the repair to last?

Many preservationists place a very high priority on "authenticity" leading them to want to reuse salvaged bricks from historic buildings. However, contemporary research has shown that there is slow removal of a small part of the vitreous binder in bricks over long periods making them slightly more porous and with somewhat reduced strength properties. Further, salt exposures from ground water or sea water contact recently have been shown to cause mineral alterations within bricks (called "diagenesis"). These factors illustrate that there are several reasons to use modern bricks for replacements.

Further on authenticity, some believe that today's shale based bricks are not equivalent to historic bricks – usually produced from alluvial clays. There is little scientific basis for this conclusion since both types of raw materials decompose forming residual minerals and a vitrified phase/binder when the bricks are fired. Having said that, it is true that historic molded bricks particularly contain elevated sand contents affecting their physical properties as discussed below. For this reason, there are engineering rationales to compare old and modern bricks based on a limited number of physical properties as discussed in the following section.

Physical Properties of Bricks Pertinent to Restoration

Introduction

Many people in the restoration community make a broad assertion that ASTM Standards for contemporary bricks do not apply to bricks for use in historic buildings. While it is true that modern standards were developed after about 1950, it is also true that modern standards reflect centuries of accumulated knowledge on brick performance. Further, the contemporary standards are incorporated in building codes making them a legal basis for actions to restore structures.

The Secretary's Standards (see above) further state, "Where the severity of deterioration requires repair or limited replacement of a distinctive feature, the new material will match the old in composition, design, color, and texture." *Composition* and *design* in engineering terms implies definition of physical properties, such as those provided in ASTM C67, *Standard Test Methods for Sampling and Testing Brick and Structural Clay Tile.*

Modern Machine Molded Bricks or "Woodmold Bricks"

The *key physical property factors* that are strategies in restoration are as follows:

1. Strength and elasticity that match the existing historic masonry so that repairs do no harm to the historic structure over long periods of time.
2. Absorption properties and suction are in desired ranges so that (a) moisture accumulation does not occur in the walls (they can "breathe") and (b) appropriately strong bonds are created between mortar and bricks.
3. The Saturation Coefficient, as calculated from absorptions, should be such that the replacement bricks are qualified for Severe Weathering service (Grade SW) or so qualified otherwise as stated in the Standards.
4. Expansion phenomena for replacement bricks are compatible with the historic masonry. This criterion includes moisture expansion and thermal expansion.

Strength and Elasticity

The compressive strengths of historic hand-molded bricks are typically in the range of 1500 – 2500 pounds per square inch (psi) while ASTM C216 for Grade SW (severe weathering) facing bricks requires a minimum compressive strength of 3000 psi average with any individual unit exhibiting a minimum compressive strength of 2500 psi. These strength differences are particularly noted by masons who term many historic bricks as "soft" since they are readily cut with a masonry saw. Some hand-molded historic bricks, however, may exceed 4000 psi in compressive strength if well-burned (highly vitrified).

Technical Note 3A published by the Brick Industry Association provides generally accepted relationships between individual brick (unit) strength and compressive strengths of masonry assemblies. For example, bricks with unit compressive strength in the range of 2400 – 3000 psi exhibit a compressive strength when tested as a mortared assemblage of 1000 psi (low strength mortar as analogous to pre Portland cement mortars). Increasing the unit compressive strength to 4400 – 5500 psi only increases the assemblage compressive strength to about 1500 psi. Thus, compressive strength of individual historic bricks likely was well sufficient in load bearing capacity for their original service in masonry construction, i.e. low compressive strength does not necessarily imply an insufficient strength of masonry in the wall.

Throughout history, the strength of bricks has been judged by their ring, i.e. the sound emitted by vibration of the unit when it is struck with a metal object such as a hammer. The vibrations of the unit are related to the elasticity or *elastic modulus* of the unit. By definition, the elastic modulus (or "elastic characteristic value") is the ratio of applied stress on the brick to the resulting strain or deformation. Well vitrified brick typically exhibit high strength and a high pitched "ring" indicating a high elastic modulus.

Technical Note 3A provides a general relationship between unit compressive strength and elastic modulus of the mortared brick assemblage as follows:

Elastic Modulus of Clay and Shale Masonry Assemblies with Type N Masonry Mortar (Technical Note 3A)	
Unit Compressive Strength, psi	**Assemblage Elastic Modulus, psi**
6000	1,600,000
4000	1,200,000
2000	800,000

The importance of the elastic modulus of units is that it is the reason for structural movements when loads are applied as from wind loads, foundation movements (as from subsidence), and imposed structural loads. It is important not to produce *differential movements* induced by repair masonry not matching the original historic masonry. Such differential movements are known to produce cracking in the masonry and eventual loss of bricks from the wall.

One well-known case of such loss occurred when a historic building (circa 1800) constructed of site made, well vitrified hand-made bricks was repaired using poorly vitrified hand-made bricks from a very small brick supplier in Mexico. Because the original bricks exhibited a significantly higher elastic modulus than the repair bricks, the repair bricks started literally falling out of the wall after about seven years of service.

Measuring elastic modulus of bricks requires specialized testing equipment. As an alternative, the compressive strength of bricks can be used as a guide to selection of replacement bricks when considering the elastic modulus criterion and Technical Note 3A. Another alternative to be considered is using the "Abrasion Index" presented as a calculated quantity in ASTM C902, *Standard Specification for Pedestrian and Light Traffic Paving Brick*, where:

$$\text{Abrasion Index} = \frac{100 \text{ X Cold Water Absorption}}{\text{Compressive Strength}}$$

In effect, elastic modulus of units is related to their strength, as higher strengths produce higher elastic modulus values. By contrast, increases in cold water absorption reduce elastic modulus. So, as is analogous to abrasion of paving bricks, lower numbers of the abrasion index indicate higher values of the modulus of elasticity. Replacement and original bricks might, therefore, be compared using the abrasion index so both have similar values of elastic modulus for brick chosen for restoration.

The values of the abrasion index can be put in perspective by using information Tables 1 and 2 in ASTM C902, where by analogy to strength specifications the following may be generally stated:

Comparison of the Elastic Modulus of Bricks Using the Abrasion Index		
Brick Characteristics	**Predicted Elastic Modulus**	**Abrasion Index**
High Compressive Strength (well vitrified)	High	≤0.11
Intermediate Compressive Strength (intermediate vitrification)	Intermediate	0.12-0.49
Low Compressive Strength (low vitrification)	Low	≥ 0.50

An alternative to estimating the elastic modulus of masonry units is direct measurement. Methods are published for refractory bricks such as ASTM C885, *Standard Test Method for Young's Modulus of Refractory Shapes by Sonic Resonance*. Alternative methods include ASTM C1419 and C1548. Estimates of elastic modulus by considering compressive strength or abrasion index should be used with care.

Absorption and Vapor Transmission

Water absorption has been used to characterize clay ceramics for thousands of years since it is a test that can be performed with simple weighing instruments and facilities for immersing bricks in room temperature or boiling water. The value of water absorption reflects the open porosity of bricks with the room temperature absorption (Cold Water Absorption) greatly affected by capillary suction, i.e. fine pores. The total absorption is obtained by boiling bricks in water for five hours (called Boiling Water Absorption), a procedure that essentially fully saturates bricks.

The potential for water vapor transmission in brick masonry is related to the permeability to vapor of the masonry mortar and that of the brick units. The central idea is to prevent water accumulation in the masonry by choosing masonry elements that allow the masonry to "breathe." For the bricks, the way to match water vapor transmission of replacement bricks with those in the historic structure and prevent water retention in small pores is to match the cold water absorption properties between historic brick and replacement bricks to the extent possible.

Some hand molded historic bricks exhibit cold water absorptions exceeding 14%. This is particularly difficult to replicate with modern machine molded or extruded bricks where the average cold water absorptions are 7.4% and 5.4% respectively (See references, Borchelt and Subasic). In such a situation, the closest match of cold water absorption is likely adequate for replacement bricks as long as the masonry mortar used with replacement bricks is similar in vapor permeability to the original mortar. Water absorption should be measured for historic bricks using the procedures in ASTM C67.

Freezing and Thawing Durability

Regardless of the physical properties of historic bricks, replacement bricks in the United States should meet Grade SW (Severe Weathering) criteria in ASTM C216 or for Canada meet Exterior Grade (Type EG) criteria in CAN/CSA-A82 unless (a) there is no concern over freezing and thawing durability in the building's location or (b) there is no weathering exposure.

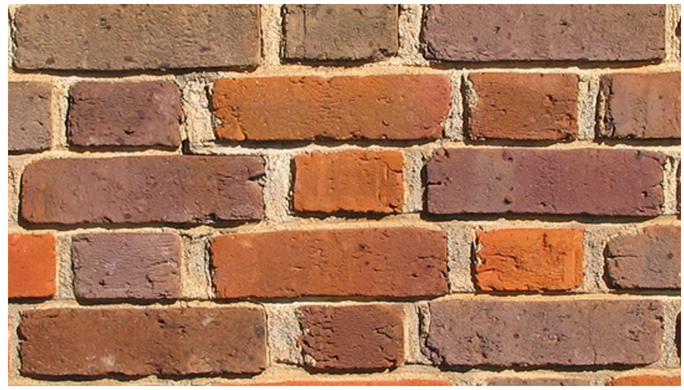
Bricks attain Severe Weathering or Exterior Grade ratings by meeting absorption criteria published in the Standards, where a Saturation Coefficient is defined as the quotient of Cold Water Absorption divided by Boiling Water Absorption, or by meeting an Alternate where the Cold Water Absorption is below a stated minimum value (Cold Water Absorption ≤ 8.0% in ASTM C216), or by passing a laboratory test for freezing and thawing as published in ASTM C67. The freezing and thawing behavior of bricks tested using methods published for concrete should not be considered since they have not been correlated with service performance for bricks.

When bricks are classed as Severe Weathering or Exterior Grade, the possibility remains that the bricks could be damaged by weathering exposure. This is because building features may allow excessive saturation in walls with examples being snow pooling, failure or absence of flashing or weep holes, excessive water impingement, or particularly severe freezing environments. In very severe exposure environments, brick manufacturers may be able to provide information on service results with a particular brand in the location of interest.

Moisture Expansion and Thermal Expansion

Moisture expansion is the increase in dimensions of bricks due to the absorption of water vapor by the units after manufacture. It is referred to as "Irreversible Moisture

Extruded Bricks Before Advent of Vacuum Extrusion
(Riggs Hall, Clemson University, 1920)



Extruded Bricks Made with Vacuum Extrusion
(Sirrine Hall,Clemson University, 1930)

Expansion" by BIA Technical Note 3A, and a generally accepted value for clay brick is 0.0003 inches/inch or 0.03%. For comparison, the expected range of moisture expansion for clay brick produced from clay, shale, or fireclay (as-defined herein) is 0.02-0.09% (ASTM C1472, Table 4). Most of the moisture absorption occurs within a few weeks after manufacture of the bricks, and bricks for restoration purposes may be specified as having been held for a minimum number of weeks prior to use in restoration.

With respect to thermal expansion, clay bricks typically exhibit a thermal expansion coefficient of 2.0 – 6.0 X 10^{-6}/°C. Hand-made bricks from coastal raw materials, however, have been shown to exhibit thermal expansion coefficients as high as 12.5 X 10^{-6}/°C, or roughly twice the value of bricks from low sand content raw materials. The value of the thermal expansion coefficient is conveniently determined by thermal dilatometry. The consequence of using a low thermal expansion coefficient repair brick in a historic structure made of coastal-made bricks is loosening of the repair masonry with possible loss of bricks from the wall.

Special Cases

A number of additional considerations are required for special service conditions. One example is salt water exposure as from ground salts, de-icing salts, sea water, or sea spray impingement. Wetting and drying cycles can lead to deterioration of bricks through salt crystallization phenomena. While it is generally true that brick characteristics that lead to good freezing and thawing durability also provide good resistance to salt crystallization, it is advisable for architects and engineers to seek guidance from a brick manufacturer on a specific brick brand/product.

Replacement bricks should be rated as "Not Effloresced" by the method in ASTM C67 to ensure that job site efflorescence will not be problematic. In many restorations, white efflorescence develops in replacement bricks due to soluble species (specifically calcium) in mortar. While this occurrence is an aesthetic problem, it can lead to cryptofluorescence damage in brick masonry (commonly known as "brick peeling"). Use of job site mortared panels exposed to ambient conditions over a period of a few weeks usually is sufficient to observe efflorescence potential. The National Brick Research Center can provide assistance in evaluating efflorescence problems. Glazed bricks may require special considerations. Forensic examination of historic glazed bricks may be required to determine the deterioration of the glazed face or of underlying problems.

Forensic Examinations of Historic Bricks and Mortar

Forensic/laboratory examinations of historic bricks and mortar used analytical and physical tests with specific purposes in mind:

- Identification of cement type and mortar or brick composition.
- Discovering any wear mechanisms from environmental exposure.

- Determining or estimating the water vapor transmission potential and other physical properties of the masonry elements.
- Obtaining information to guide in the selection of replacement materials.
- Providing information regarding alterations to historic structures (such as additional insulation).

The forensic studies by materials scientists utilize analytical techniques that are usually unfamiliar to architects and structural engineers. These techniques include chemical analysis, mineralogical analysis, determination of water soluble salt content, porosity characterization, and microscopy. It is the job of the materials scientist to provide practical advice to architects and engineers in terms of authenticity, properties, and potential performance of historic and replacement materials.

Specifying Bricks for Restoration

An important idea for restoration professionals and architects is that any specification for replacement bricks needs only to be as detailed as necessary to meet the aesthetics of the historic structure. A detailed list of physical properties with very low tolerances is not compatible with the restoration job at hand and is not acceptable for the brick manufacturer. Masonry walls are tolerant of small differences in physical properties. The important or key physical properties for restoration are given above as selected from all of the many possible physical properties that are not necessary for restoration.

In one recent restoration of a historic fort, the brick manufacturer was asked to meet specific absorption and elastic modulus values. The manufacturer declined the order on those terms, as they did not want to guarantee specific values. Having said that, manufacturers of hand molded bricks should be willing to meet certain physical ranges such as for cold water absorption and coefficient of thermal expansion in reasonable limits.

Paving bricks represent a special case for restoration. Replacement paving bricks should meet Standards for the intended application – such as light duty or heavy vehicular paving.

Extruded Bricks with Rockface (lower)

Conclusions

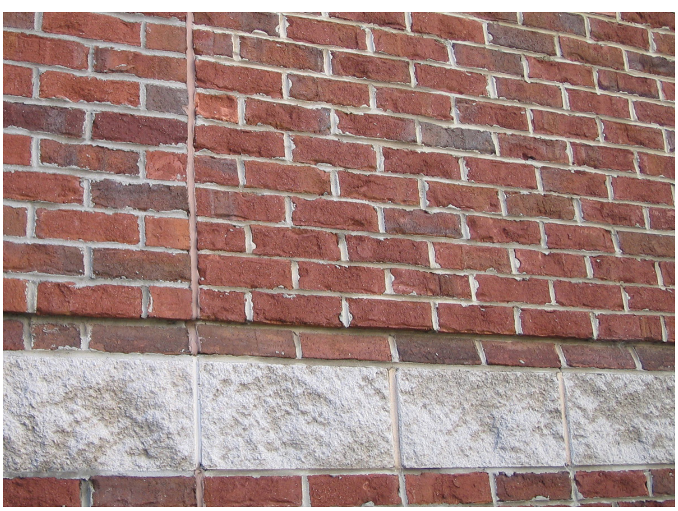
Any restoration effort should be preceded with a safety assessment of the historic structure by qualified structural engineers. Bricks from the historic structure should be characterized as to strength, absorption, and thermal expansion using methods in ASTM C67 and elsewhere in the Standards. Forensic examinations of historic materials may be required to determine compatibility of replacement and historic materials.

Replacement bricks for restoration of historic buildings should meet the aesthetic criteria of the historic structure to include color (color range), physical dimensions, and surface features. In many cases, bricks from the same manufacturing methods for historic and replacement bricks, in terms of forming of bricks, allows aesthetic considerations to be attained. The mortar used in restoration should provide a similar color as the original mortar, and it should be chosen using the guidelines in ASTM C1713. Prior cleaning of the historic structure should be carefully considered and follow established procedures, if employed.

It is important to specify bricks for restoration that generally exhibit similar physical properties as the original bricks in the structure. The most important properties are compressive strength, cold water absorption, and thermal

Dry Pressed Facing Bricks with "Thinline" Mortar Joints

expansion coefficient. An estimate of the Modulus of Elasticity is advisable for replacement bricks so that they are similar to that of the historic bricks. It is unnecessary to provide many other physical properties due to the nature of the masonry walls. Bricks qualified for Severe Weathering or Exterior exposures should be used unless exposure conditions allow bricks otherwise graded for replacements. Salvaged bricks should not be used in restoration without expert engineering advice.



Modern Extruded Bricks Produced to Resemble Woodmold Bricks (Dormitory, Clemson University, about 2000)

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The Bishop Materials Laboratory received accreditation on November 21, 2013 from the International Accreditation Service (see page 18).

International Accreditation Service

CERTIFICATE OF ACCREDITATION

This is to signify that

THE BISHOP MATERIALS LABORATORY
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Testing Laboratory TL-504

has met the requirements of the IAS Accreditation Criteria for Testing Laboratories (AC89), has demonstrated compliance with ISO/IEC Standard 17025:2005, *General requirements for the competence of testing and calibration laboratories*, and has been accredited, commencing November 21, 2013, for the test methods listed in the approved scope of accreditation.

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Print Date: 12/3/2013

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