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Growth of Brick in Freezing Climates
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Abstract

In the maintenance of existing traditional brick buildings, one will occasionally encounter the presence of cracks whose formation does not conform to the application of service loads, thermal expansion, or other commonly understood behaviors of brick walls. Upon examination one can find these cracks in the face material do not extend through the wall. Such cracks are the result of volumetric expansion of backup brick. Such growth in backup brick can occur through a phenomenon known as freeze growth. This phenomenon is consistent with brick structures where exposure of elements can readily freeze especially in more exposed parts–parapets, belfries, unheated towers, and the like. Buildings that are finished with plaster readily transmit building heat to the exterior thereby limiting the chance of freezing in backup brick. Renovated buildings in which new insulation is applied to the interior face of walls will move the freezing point deeper into the wall thereby increasing chances of cracks developing in face brick because of backup freeze growth. This report summarizes the writer's knowledge and experience of freeze growth.

Background

Traditional Brick Masonry

Until the early half of the 20th Century, most brick masonry consisted of layers of brick to make up the entire wall structure. Clay is usually the principal ingredient in brick. Brick is fired in an oven to fuse the clay together to give it ceramic strength and harness. Exterior walls generally varied from three (12 inches) or more layers. The outermost layer is typically made with "face" brick and backed up with common brick. Face brick tended to be a higher quality and more expensive material. Designers sought face brick for its aesthetic appearance and superior firing to better wear against harsh weather.

Traditional designers assumed face brick would protect the weaker backup brick. Common brick can usually be distinguished from face brick as less firing at the kiln would produce a paler color. In addition to being a different brick material, masons often would use thicker mortar beds for backup (for economy) than those for face brick using one less course every eight to ten courses where bedding planes rejoined to accommodate header courses. The above practices resulted in masonry walls made of a facing layer and a backup layer acting compositely but with differing properties.

Brick properties

The term brick includes modular units set in mortar to construct walls, columns, and arches which serve to resist compressive forces. Beside clay, units can be made from shale, lime, and concrete. The clay bricks are by far most common in stately buildings. Builders routinely test bricks to understand their pore structure, saturation, and freeze thaw cycles to determine their suitability for long-term wear. Most designers understand that brick right out of the kiln is completely dry and over time will absorb atmospheric moisture. This absorption will result in the slight irreversible growth of clay brick. This is a process in which the rate diminishes over time. Most of the growth is completed in seven and one half years and totally complete after fifteen years.

At the same time, most designers are unaware that under certain conditions backup brick can expand thereby stretching and cracking the face brick. This is a result of backup brick freezing while saturated. It can happen any time in the life of a structure once certain conditions are met with saturation at around 14°F. One must appreciate that moisture will wick through a brick wall through capillary action and balancing of vapor pressures seeking equilibrium from wet to dry.

Water to ice transition

Most materials contract as temperature drops. Water is an exception. As the temperature drops water contracts. At freezing (32°F) water transitions to ice and still contracts. At about 27.33 °F ice begins to expand as the temperature continues to drop. At 13.46°F ice begins to contract as temperature drops.

The importance of this property is that brick contains pores which can hold water. When saturated, the stress on ice expanding will expand the brick. This expansion is a plastic phenomenon in which the dislocation in the brick is permanent. This can repeat over numerous cycles increasing the expansion over a long time.

BIA Technical Notes 18A

The Brick Industry Association (BIA) publishes technical notes. One is Technical Notes 18A – Design and Detailing of Movement Joints, Part 2 (TN 18A). This note discusses the calculation of movement due to various effects such as moisture expansion, freezing expansion, and thermal expansion. Below is an excerpt from TN 18A that gives one a sense of the contribution of each of the three components of expansion.

> The design value of the coefficient of moisture expansion for clay masonry is usually 0.0005 in./in. The coefficient for thermal expansion is 0.000004 in./in./°F. The coefficient of freezing expansion is taken as 0.0002 in./in. Freezing expansion does not occur until wall temperatures go below 14°F (-10°C). Further, the units must be saturated when frozen to cause expansion. Local conditions must be considered to determine if freezing expansion will occur, but is usually considered negligible

L.A. Palmer testing in 1931

The U.S Department of Commerce published a paper Volume Changes in Brick Masonry Materials by L. A. Palmer in June 1931. Palmer tested various brick and mortar assemblies by setting three bricks end to end separated by mortar joints. He included mortar to account for the difference in materials and the shrinkage of mortar as it cured. Palmer concluded that repeated freezing and thawing increased pore size and consequently the extent of saturation leading to a permanent increase in size. The increase amounted to 0.0002 inches per inch for soft burned brick and about 0.00005 inches per inch for hard burned brick. These figures represent eight to ten cycles for soft burned brick and five cycles for hard burned brick.

J.I. Davidson in 1980

The Second Canadian Masonry Symposium included a paper Linear Expansion Due to Freezing and Other Properties of Bricks by J. I. Davison in 1980. Davison tested 13x13x76 mm samples cut from various bricks. Davison was mainly looking to identify failure where samples fractured but included expansion measurements of specimens. The tested samples came from buildings where they had been in service. The samples were given 50 cycles of testing. He measured permanent expansion in the range of 0.00001 to 0.00059 inches per inch.

Author's experience

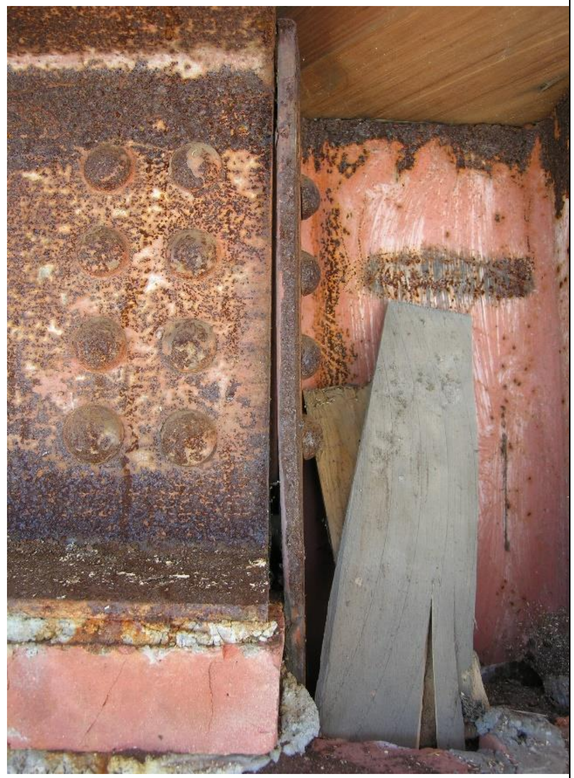
In 2006 demolition started on a 20-foot square steel framed tower with common brick infilling the steel frame and face brick enclosing the frame. Before demolition, cracks were present in the corners of the tower. After face brick was removed at a spandrel beam level, I could see that brick had pushed against the steel columns dislocating the column flanges by one-quarter inch at each corner. The columns are spaced 18 feet center to center. The one quarter in deformation is from brick growing over nine feet. This figures to 0.0023 inches per inch. This figures to 11.5 times Palmers testing and 3.89 times the maximum figure tested by Davison. It is 11.5 times the amount recommended by the BIA in their TN 18A.

The author was once asked to look into cracking on a renovated brick building where insulation had been added to the interior. The cracks were generally located over arch windows where continuous brick spandrels were least wide floor to floor. The backup brick continued to span over arch windows behind cracked facing.

The author has seen a whole gable wall face of a 210-year-old brick building with a horizontal crack in the facing at the eave level indicating the now cold attic backup brick expanded and lifted the facing. The attic was no longer heated as it was abandoned ten years earlier.

The above examples are all consistent with facing cracked from expanded backup brick.

The author has also seen brick buildings left abandoned for more than twenty years show no evidence of cracking. In one such building, the backup brick was as well burned as the face brick.

	
Backup brick pushing against column under spandrel beam at southwest corner. Column flange dislocation is ¼ inches.	Backup brick pushing against column under spandrel beam at southeast corner. Column flange dislocation is ¼ inches.

Implications for Maintenance

Code

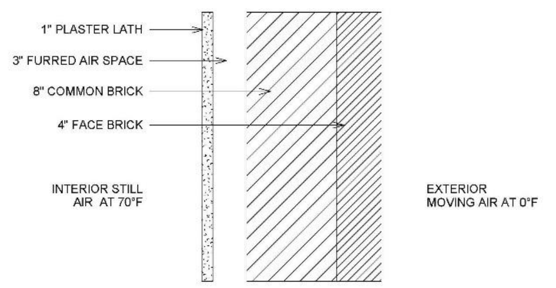
Specification code writing authorities invest their efforts in proscribing modern practices. Most brick use now is a veneer use. The concern for brick backup use is not a prime concern. The code specifications are generally intended for face brick use. Face brick is generally a higher quality brick than common brick used to build in the 18th, 19th, and early 20th centuries. The implication is that properties listed in codes are for materials with a better quality than used for common brick in older buildings.

ACI 530 Building Code Requirements for Masonry Structures is the accepted standard for masonry design. In Section1.7.4 Other Effects, this Code places the responsibility on the designer to take into consideration other effects including expansion and creep. One has to refer to the Brick Industry Association Technical Notes 18A (TN 18A) to actually learn about freeze expansion. TN 18A makes a very brief reference to freezing, but it’s there. Additionally, in the writer’s opinion the freezing coefficient reference is made for control joints in modern veneer brick. In the writer’s opinion, this coefficient is not valid for backup brick.

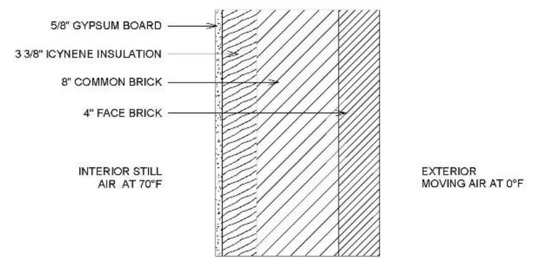
Wall temperature gradient analyses

Presented here is the analyses of a traditional brick wall and a typical renovated wall with insulation added. Present day designers are typically using icynene spray insulation that expands to fill a furred cavity. These analyses reference *Thermal and Moisture Protection Manual* by Christine Beall for material properties and methodology for gradient analyses.

Traditional Brick wall with plaster



Renovated traditional wall insulated



Component	T	R/in	R	T	Ti	Component	T	R/in	R	T	Ti
Interior still air			0.68	10		Interior still air			0.68	3	
Plaster & lath	1	0.64	0.64	10	60	Gypsum board	5/8		0.56	2	67
Furred air space	3		1.14	18	50	Icynene insulation	3 1/2	3.7	12.95	56	65
Common brick	8	0.15	1.20	18	32	Common brick	8	0.15	1.2	5	9
Face brick	4	0.18	0.72	11	14	Face brick	4	0.18	0.75	3	4
Ext. moving air			0.17	3	3	Ext. moving air			0.17	1	1
Totals			4.55		0	Totals			16.28		0

T equals thickness in inches, R/in equals thermal resistance per inch, R equals thermal resistance (°F/Btu/h-ft^2), T equals temperature drop per component, and Ti equals the temperature at interface.

The temperature in the common brick backup in the traditional brick wall ranges from 32°F down to 14°F placing this component in the safe zone above the critical temperature of 14°F. Whereas the backup brick in the renovated and insulated wall places it in the range 9°F down to 4°F, well below the critical freezing temperature. Some icynene insulations have even a higher R value exacerbating the condition.

Heat

The best defense of preventing damage from brick expansion due to freeze growth is to allow building heat to be lost through exterior walls. When existing buildings that show evidence of cracking even though uninsulated, the author recommends maintaining a 70-degree indoor temperature when forecasts call for temperatures below 20°F. Although the critical freezing temperature appears to be 14°F, use 20°F to guard against error.

Insulation

Where renovation programs call for improving energy efficiency, consider adding additional insulation on roofs and non-brick areas of the building envelope along with better thermally performing windows. If wall insulation is still desired, test backup brick and examine its degree of firing. Hard burned backup will lower the risk. Still, use as little insulation to meet energy goals on brick walls knowing that saturated backup brick will risk expansion at 14°F.