Freeze-Thaw Damage
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Freezing Temperatures
Water
Susceptible Brick
Susceptible Brick
Firing Temperature
Vitrification
Kelvin Equation

\[
\ln \left( \frac{p}{p_0} \right) = \frac{2\gamma V_m}{rRT}
\]
Calculating capillary rise

\[ h = \frac{2 \sigma \cos \theta}{g \rho r} \]
Capillary rise versus diameter
1. Evaporation

Water with salt in solution travels in porous material via capillary flow to surface where evaporation occurs.

2. Salt is left behind as water evaporates; process leads to an ever-increasing concentration of salt as evaporation continues.

3. Water rushes to dilute concentration of salt leading to potentially huge hydrostatic pressures.

4. “Spalling”

Surface breaks apart and flakes when hydrostatic pressure due to “osmosis” exceeds cohesive strength of material.
Diffusion + Capillarity + Osmosis = Problem

- Diffusion Vapor Pressure: 3 to 5 psi
- Capillary Pressure: 300 to 500 psi
- Osmosis Pressure: 3,000 to 5,000 psi
Mortar “eaten” away as drying happens from within the mortar matrix

Salts left behind on surface in the form of crystals (“efflorescence”)

Evaporation from surface film of water

Capillary flow of salts in solution
Lime mortar “eaten” away over time “sacrificing” itself to protect brick and masonry units

Evaporation from thick lime-based mortar rendering

Capillary flow of salts in solution
Wood floor framing embedded into masonry wall

Stainless steel cap flashing regletted into exterior wythe

Vapor impermeable layer to prevent evaporation or drying inward

$1.5 \chi$

Sacrificial layer

$\chi$

$\frac{3}{4} \chi$

Sacrificial layer

Sacrificial layer
Subfloor held away from wall

Timber decking cut back from wall

Spray applied foam insulation (2" closed-cell, high-density)

Uninsulated steel stud assembly

Gypsum board

Subfloor held away from wall

Timber decking cut back from wall

Plywood subfloor

Exterior wythe (repointed or coated with polymer cement slurry)

Multi-wythe masonry wall

Embedded wood timber floor structure
Multi-wythe mass wall

Interior lining (gypsum board)

Interior framing

Spray-applied polyurethane foam (2 lb/ft³ density)
Multi-wythe mass wall

Interior lining (gypsum board)

Cellulose or fiberglass cavity insulation

Wood frame wall (2x6)

Fluid-applied water control layer (vapor semi-permeable)
Multi-wythe mass wall

Interior lining (gypsum board)

“Strapped wall”; horizontal framing

Membrane “smart vapor barrier”

Cellulose or fiberglass cavity insulation

Wood frame wall (2x6)

Fluid-applied water control layer (vapor semi-permeable)

Cementitious rendering
Liquid applied membrane waterproofing

Flanged window

Trim closure

Concrete sill

2x6 wood buck

Exterior wythe (repointed or coated with polymer cement slurry)

Multi-wythe masonry wall

Air seal

1 1/2" rigid insulation

Plywood spacer

1x2 backdam

2" spray applied foam insulation (closed-cell, high-density)

Uninsulated steel stud assembly

Gypsum board
Stucco
Traditional Lime Stucco  
Lime/Portland Cement Stucco  
Portland Cement Stucco  
Polymer Modification  
Greater than 20 perms  
5 to 10 perms  
1 to 5 perms  
Less than 1
Horizontal “scoring” provides mechanical bond and “shelf” for water during “wet” curing
Figure 1c. Gypsum, hydrated from plaster of paris and water, porosity 30 per cent.

Figure 1b. Brick, sintered clay, porosity 40 per cent.
Ancient Modification Additives

Cow Dung
Egg Whites
Pig Blood
Stainless steel flashing

Trim

Paver

Waterproofing extended up wall to reglet

Drainage mat

Waterproofing
Stainless steel flashing

Reglet

Plaster “filler” for slope

Cladding “offset”
Parapet cap flashing sloping to interior with drip edges

Parapet flashing

Slope

Drip

Plaster “filler” for slope supporting flashing
1x4 wood furring attached through rigid insulation to 2x4 wood furring

2x4 wood furring mechanically attached to masonry wall

Fluid-applied water control layer and air control layer

Cladding

Joints offset horizontally and vertically with each layer taped

Masonry wall

Interior plaster and lath
2" semi-rigid mineral fiber insulation; seams offset horizontally and vertically

2x4 wood furring mechanically attached to masonry wall

Fluid-applied water control layer and air control layer

Metal hat channel

Fiber cement panel

"Reveal" in panel joint

Spacer/joint backer

1 1/2" semi-rigid mineral fiber insulation

Masonry wall

Interior plaster and lath
From the US Army Corps Engineers Extreme Frost Penetration (in inches) based on state averages.