Freeze-Thaw Damage
Freeze-Thaw Damage
Freezing Temperatures
Water
Susceptible Brick
Susceptible Brick
Firing Temperature
Vitrification
The graph shows the relationship between strain and degree of saturation. The critical degree of saturation, $S_{crit}$, is approximately 0.7.
Kelvin Equation

\[ \ln \frac{p}{p_0} = \frac{2\gamma V_m}{rRT} \]
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**
   Salt is left behind as water evaporates; process leads to an ever-increasing concentration of salt as evaporation continues.

3. **Water Rushes**
   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.
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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)

“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)

Cementitous 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
Traditional Lime Stucco: Greater than 20 perms
Lime/Portland Cement Stucco: 5 to 10 perms
Portland Cement Stucco: 1 to 5 perms
Polymer Modification: 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
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

Fiber cement panel

2x4 wood furring mechanically attached to masonry wall

"Reveal" in panel joint

Fluid-applied water control layer and air control layer

Spacer/joint backer

1½" semi-rigid mineral fiber insulation

Masonry wall

Metal hat channel

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