Freeze-Thaw Damage
Freeze-Thaw Damage
Freezing Temperatures
Water
Susceptible Brick
Susceptible Brick
Firing Temperature
Vitrification
$S_{crit} \approx 0.7$
Calculating capillary rise

\[ h = \frac{2 \sigma \cos \theta}{g \rho r} \]

\[ P_{\text{cap}} \]

\[ P_0 \]

\[ \theta \]

\[ z \]

ambient pressure

\[ \Delta z \]

\[ g \rho \Delta z \]

\[ \frac{2 \sigma \cos \theta}{r} \]

pressure
Capillary rise versus diameter
Surface area vs. particle size
From Straube & Burnett, 2005
Figure 1c. Gypsum, hydrated from plaster of paris and water, porosity 30 per cent.

Figure 1b. Brick, sintered clay, porosity 40 per cent.
Stucco rendering

Masonry wythe

Vertical wood furring

Plaster and lath

Exterior

Interior
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 Pressure**
   - 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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Capillary break on exterior foundation wall

Capillary break under slab

Capillary break on top of footing
Coping/cap flashing over top of parapet

Embedded wood timber roof structure

Exterior wythe (repointed or coated with polymer cement slurry)

Multi-wythe masonry wall

Fully-adhered membrane roofing extending up interior and over top of parapet wall

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

Timber decking

2" sprayed cellulose fire-proofing ("K-13")

Dropped ceiling structure

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

Uninsulated steel stud assembly

Gypsum board
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
Multi-wythe mass wall

- Interior lining (gypsum board)
- Interior framing
- Rock wool or Roxul rigid mineral wool insulation
- Fluid-applied water control layer (vapor semi-permeable)
- Cementitious rendering
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)
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
Roof overhang screens wall (deflects rain)

Site grading slopes ground away from building over entire perimeter
Rain water falling on roof is collected in gutters.

Overhang protects the ground around the foundation from getting saturated.

Down spouts carry rainwater from the roof away from the foundation.

Capillary break under plate.

Polyethylene vapor diffusion retarder in direct contact with concrete slab.

Granular drainage pad (coarse gravel, no fines).

- Keep rain water away from the foundation perimeter.
- Do not place sand layer over polyethylene vapor diffusion retarder under concrete slab.
- Where vinyl flooring is installed over slabs, a low water-to-cement (w/c) ratio (≤ 0.45 or less is recommended) to reduce water content in the concrete; alternatively, the slab should be allowed to dry (less than 0.3 grams/24 hrs/ft²) prior to flooring installation.
Rain water falling on roof is collected in gutters

Overhang protects the ground around the foundation from getting saturated

Flash roof into gutter

Down spouts carry rainwater from the roof away from the foundation

Capillary break under plate

Ground slopes away from the foundation

Conditioned space

Polyethylene ground cover acting as both an air barrier and a vapor barrier

Interior grade of crawlspace higher than surrounding grade

- Keep rain water away from the foundation perimeter
- If the interior crawlspace is lower than the exterior grade, a sub-grade perimeter footing drain is necessary as in a basement foundation
- The crawlspace is conditioned space; it is part of the "interior" of the building and should be heated, cooled and ventilated as part of the building's heating, cooling and ventilating strategy
Rain water falling on roof is collected in gutters.
Overhang protects the ground around the foundation from getting saturated.
Flash roof into gutter.
Down spouts carry rainwater from the roof away from the foundation.
Ground slopes away from the foundation.

Concrete foundation wall.
Groundwater flow is downward (not horizontal) under the influence of gravity to the perimeter drainage system.
Capillary break over footing.
Slab isolation joint.
Polyethylene vapor diffusion retarder.
Granular drainage pad (coarse gravel, no fines).
Pipe connection through footing contracts exterior perimeter drain to granular drainage pad under basement slab.

- Keep rain water away from the foundation perimeter.
- Drain groundwater away in sub-grade perimeter footing drains before it gets to the foundation wall.
Perforated drain pipe added to "T" in order to couple sub-slab pressure field to vent stack.
Remove windows and infill openings

Remove demising wall

Add column support

Basement

Crawlspace
3” spray polyurethane foam (2 lb/ft³ density)

1 1/2” metal stud wall

Gypsum board thermal barrier

3/4” drainage mat (filter fabric side facing up)

2” extruded polystyrene (XPS)

New concrete slab

Existing slab
Vapor semi-permeable assembly allows moisture to pass in a slow, controlled manner.
Carpet or wood floor (avoid vinyl flooring as vinyl flooring does not breathe)

3/4" plywood (T&G — narrow edges "biscuit" joined)

Rigid insulation (extruded polystyrene — uniaxial, no polypropylene or foil facers)

Air space

Dimpled plastic sheet membrane (air tight and gas tight)

Existing slab

Damp ground
(no capillary break, no polyethylene ground cover)

Vapor pressure on top of slab and under slab equalizes, thereby stopping capillary transfer of water and soluble mineral salts (moisture content in air space and under slab remains the same; i.e. "wet")
Plain
Hollow Back
From the US Army Corps Engineers Extreme Frost Penetration (in inches) based on state averages.