Joseph Lstiburek, Ph.D., P.Eng, ASHRAE Fellow

Building Science

Foundations

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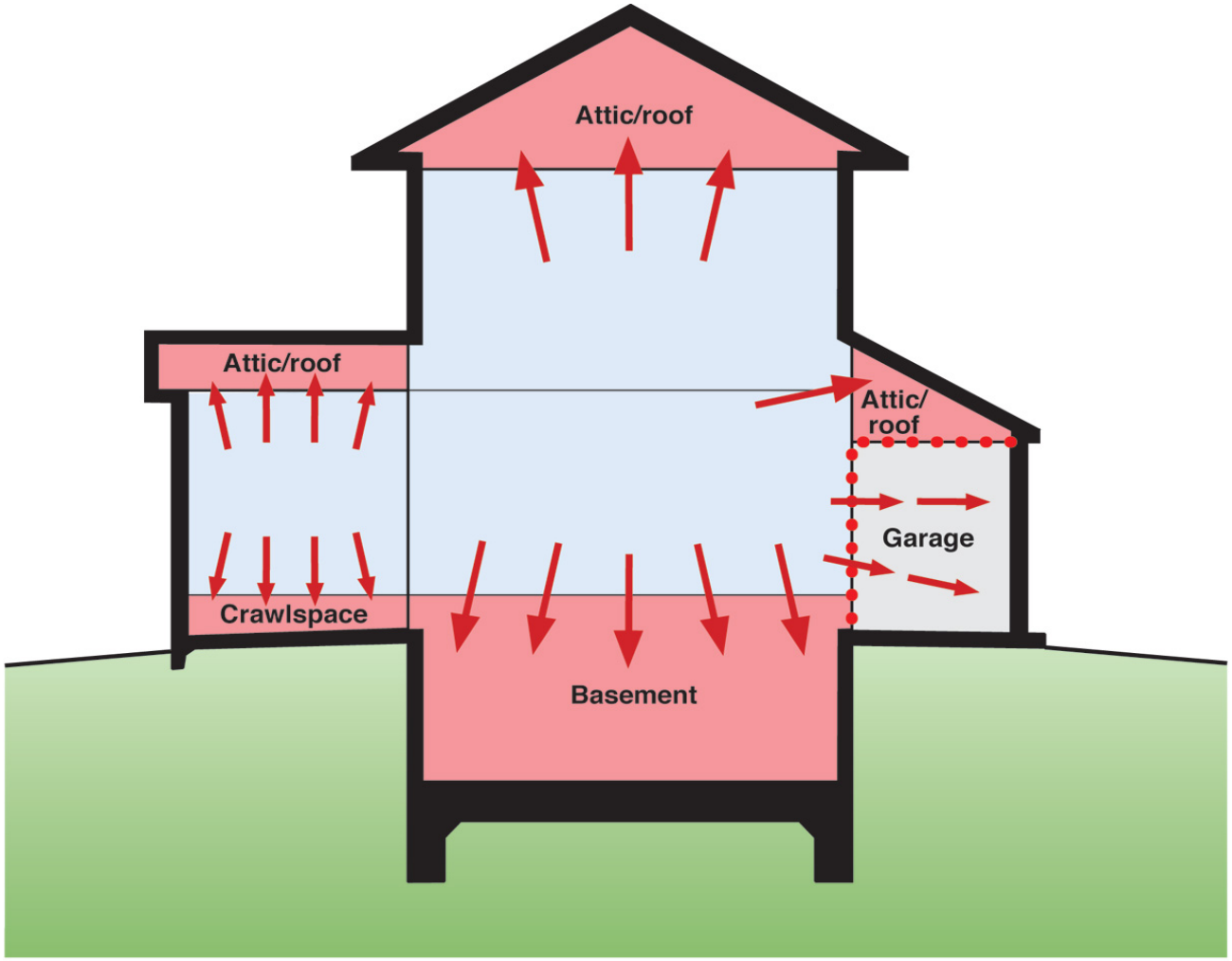
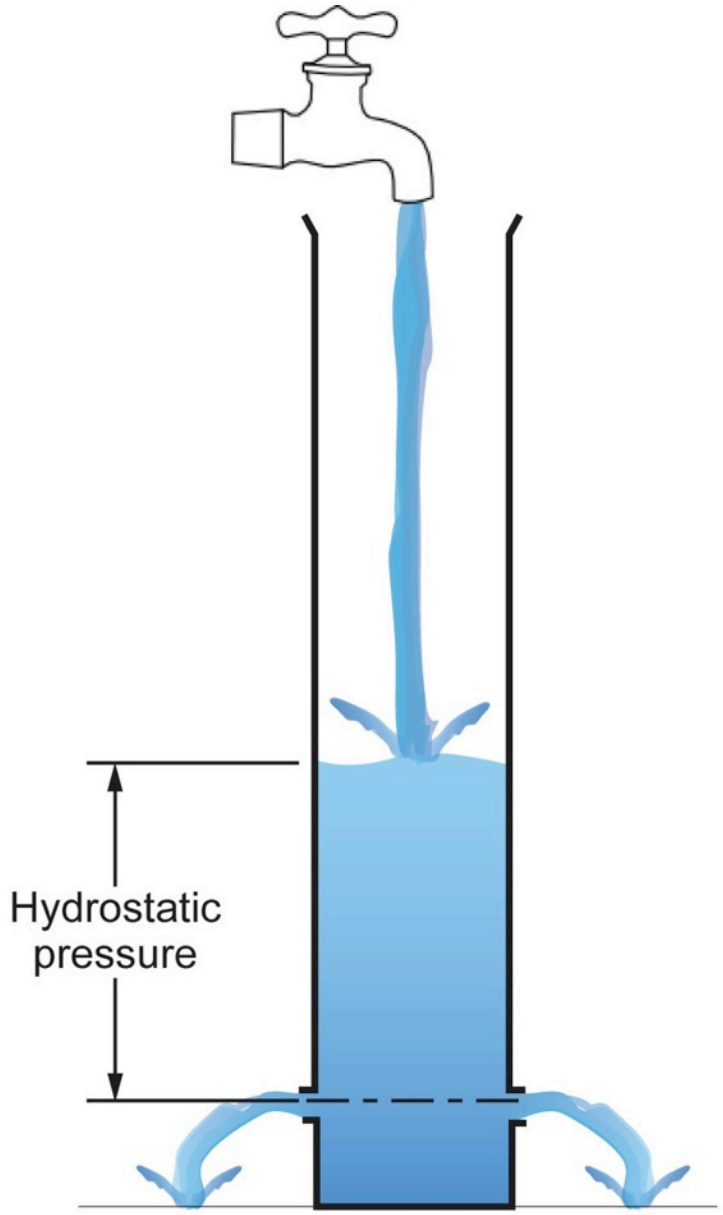


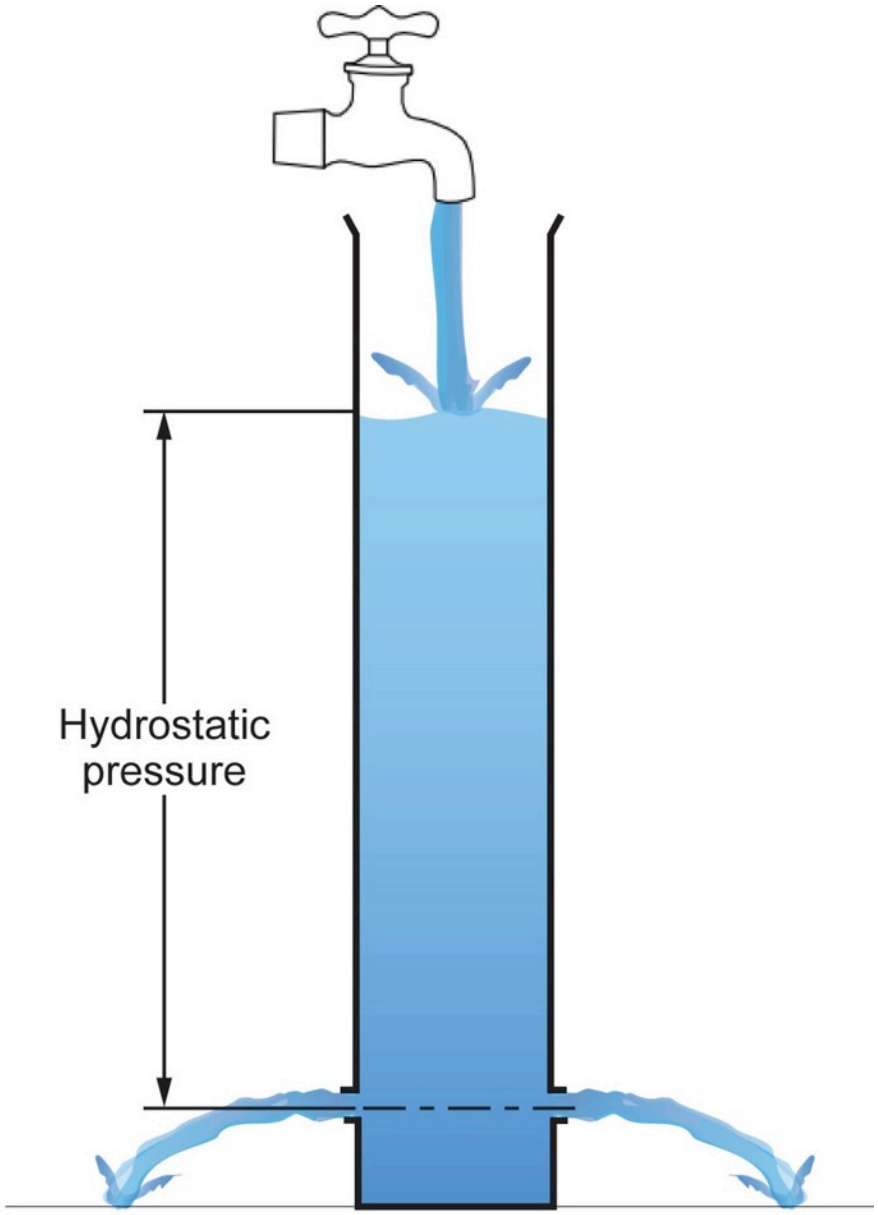
Expansion of Conditioned Space

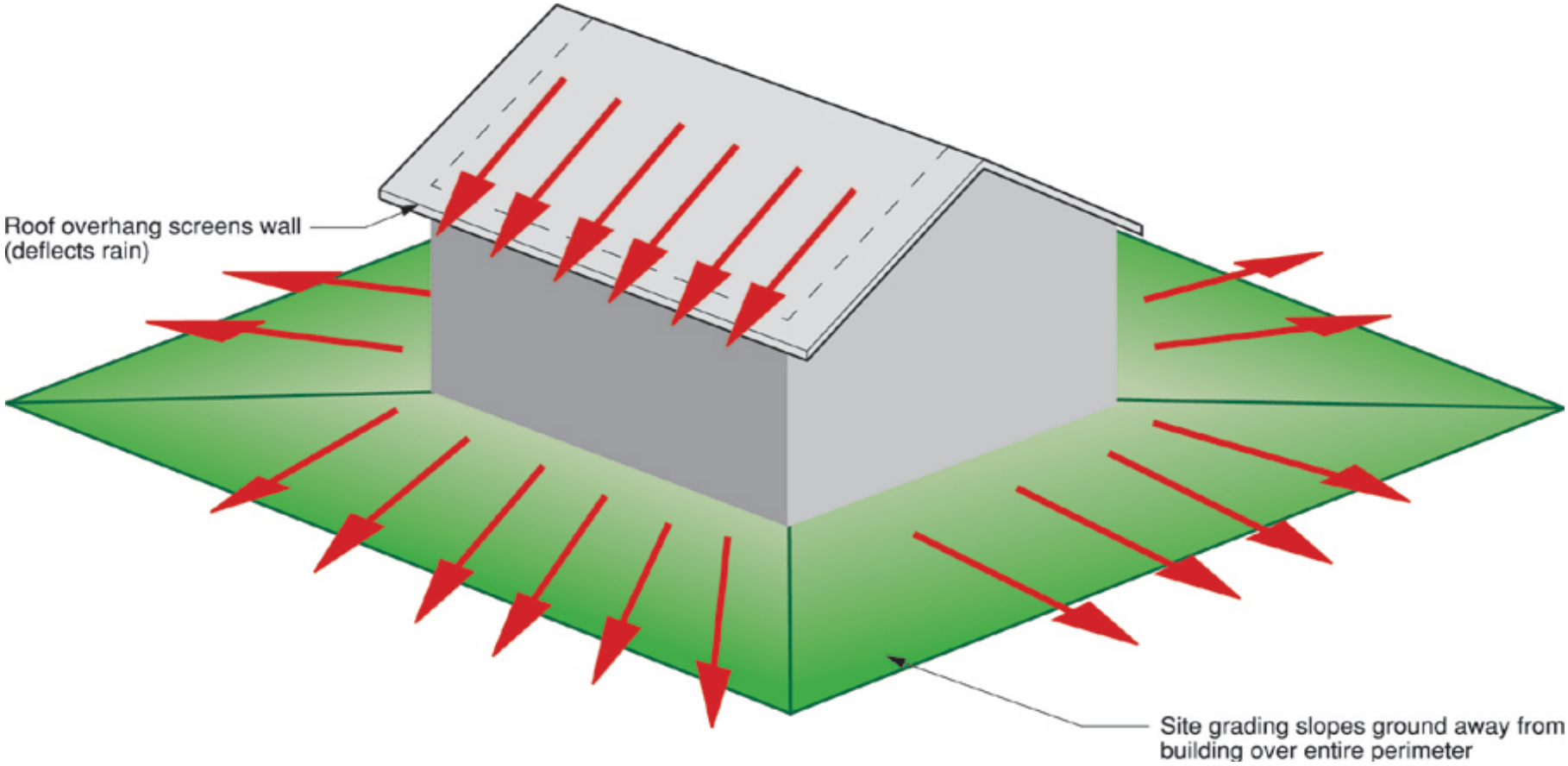
- Conditioned space boundaries moving towards exterior surfaces of building
- Garage isolated from house by air barrier/pressure boundary
- Garage ventilated and conditioned independently of rest of conditioned spaces

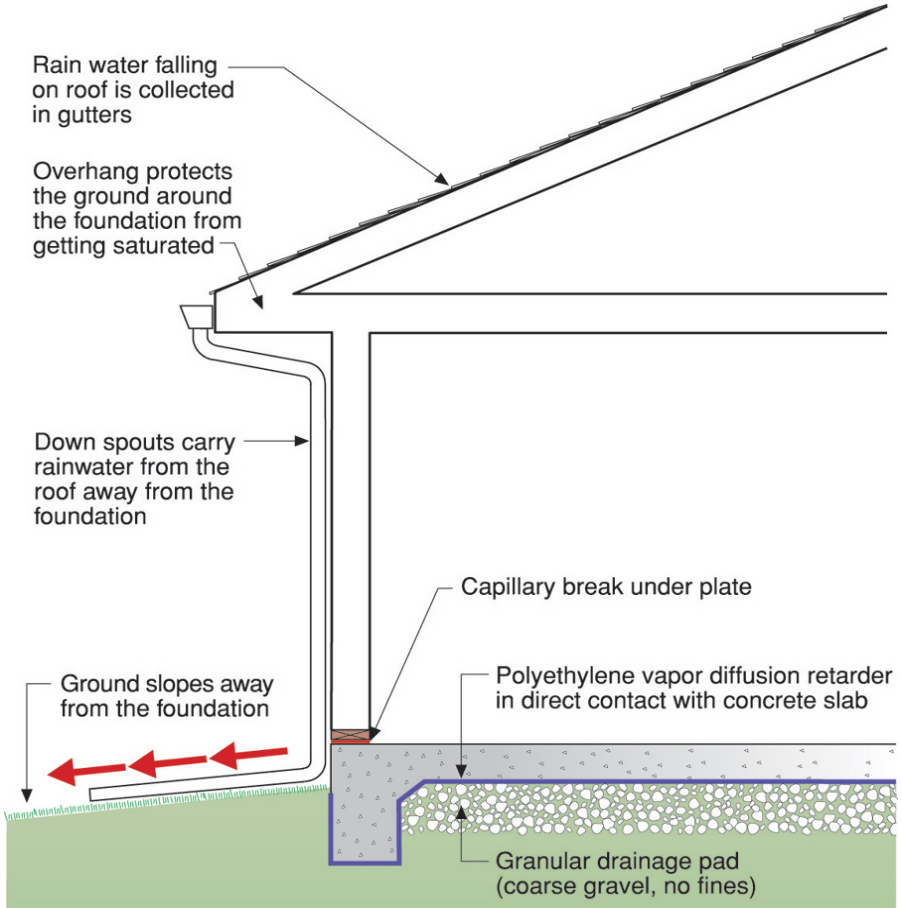
Mechanisms of Flow

• Liquid	Gravitational	Hydrostatic Pressure
	Capillary	Suction Pressure
	Osmosis	Solute Concentration
• Vapor	Diffusion	Vapor Pressure
	Convective	Air Pressure

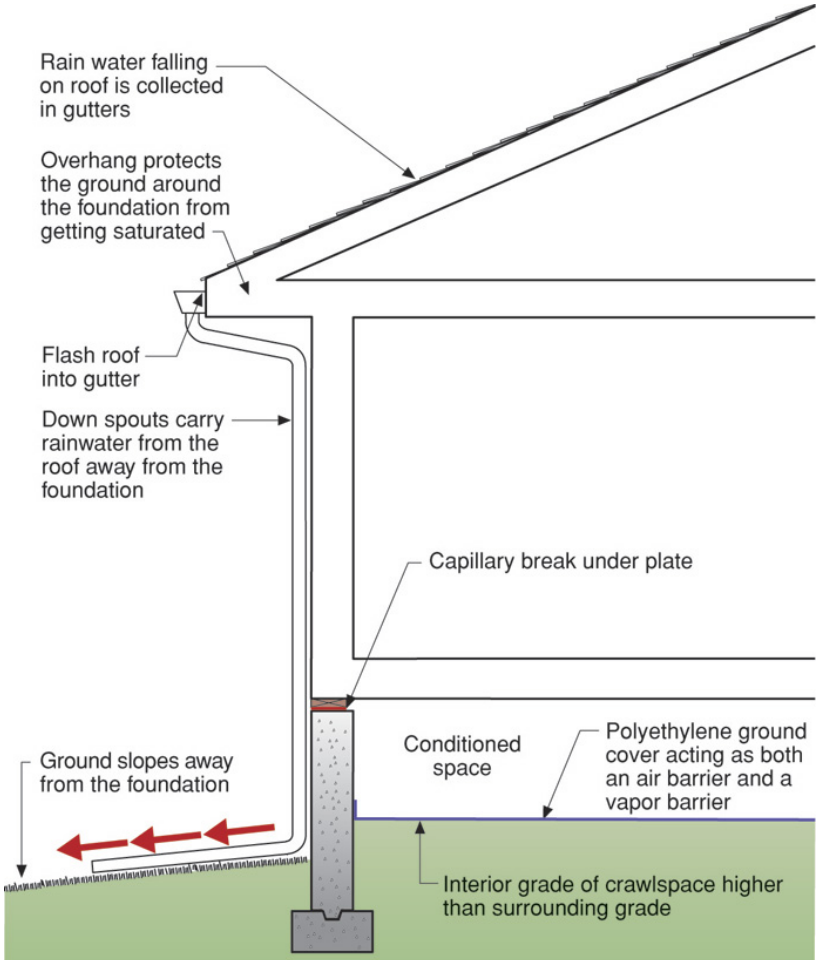

Hydrostatic
pressure


Hydrostatic
pressure

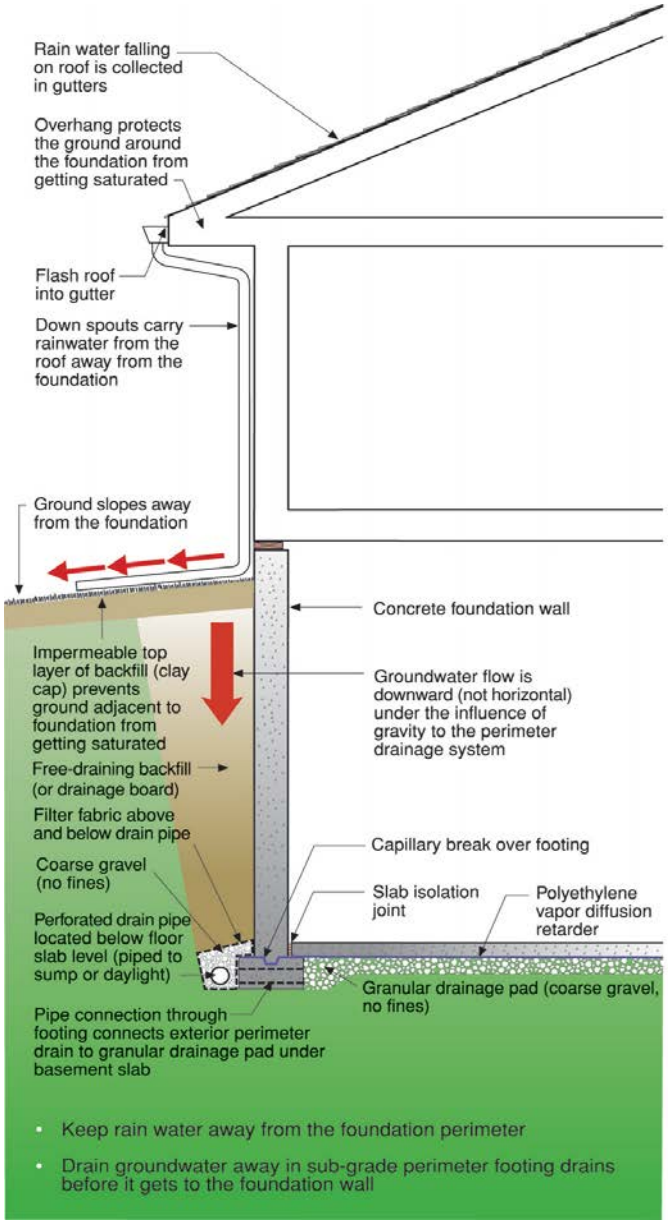

Roof overhang screens wall
(deflects rain)
Site grading slopes ground away from
building over entire perimeter



- 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/ft^2) prior to flooring installation

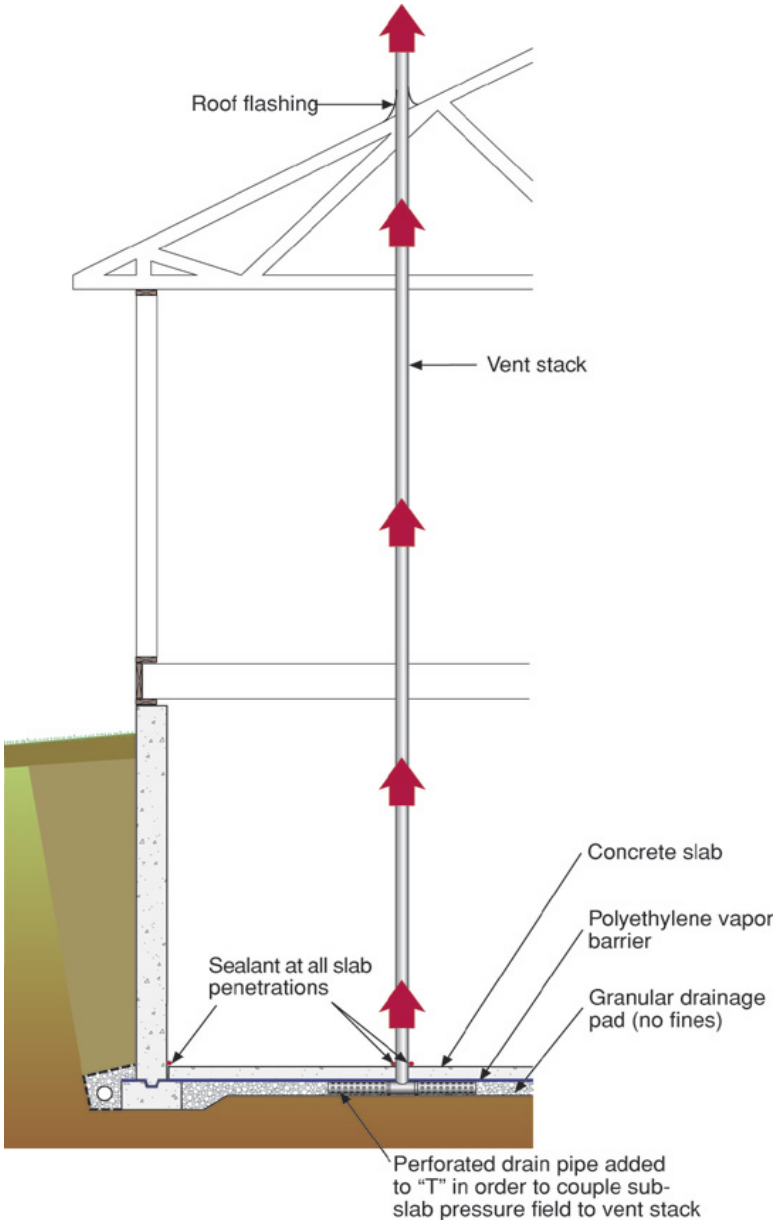


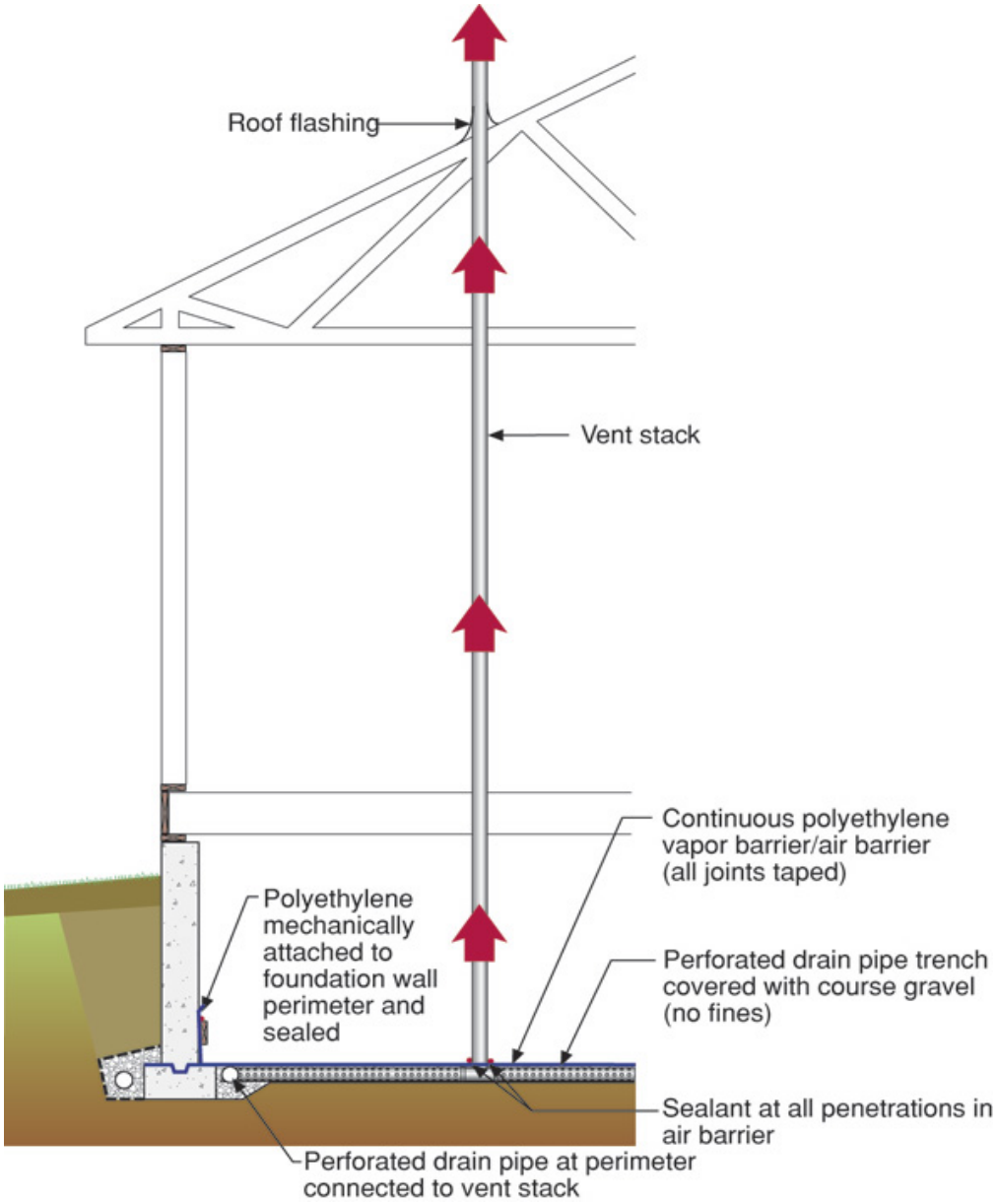
- Keep rain water away from the foundation perimeter
- If the interior crawlspace is lower than the exterior grade, a sub-grade perimeter footing drain is necessary as in a basement foundation
- The crawlspace is conditioned space; it is part of the "interior" of the building and should be heated, cooled and ventilated as part of the building's heating, cooling and ventilating strategy

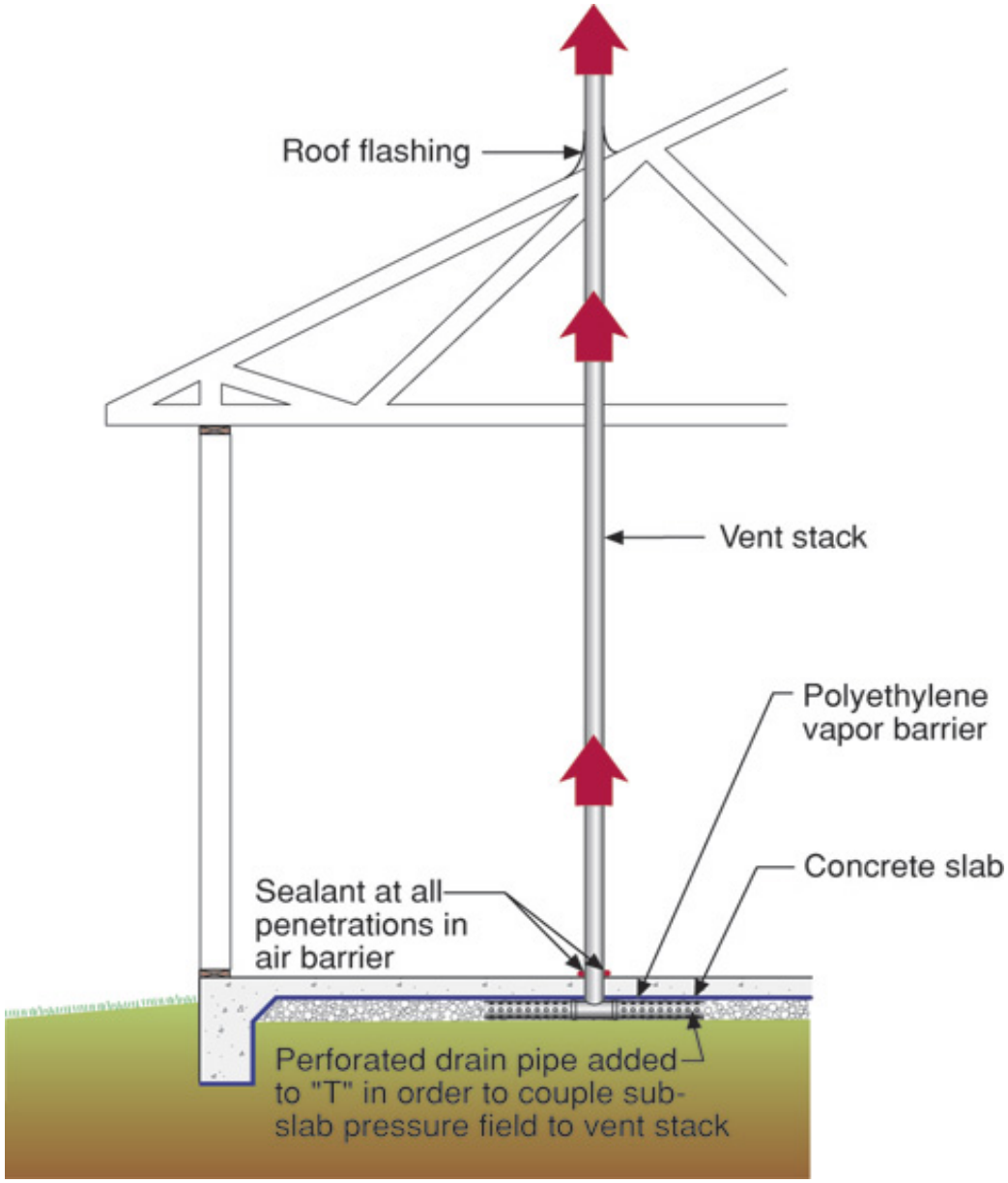

Rain water falling on roof is collected in gutters
Overhang protects the ground around the foundation from getting saturated
Flash roof into gutter
Down spouts carry rainwater from the roof away from the foundation
Ground slopes away from the foundation
Concrete foundation wall
Impermeable top layer of backfill (clay cap) prevents ground adjacent to foundation from getting saturated
Groundwater flow is downward (not horizontal) under the influence of gravity to the perimeter drainage system
Free-draining backfill (or drainage board)
Filter fabric above and below drain pipe
Capillary break over footing
Coarse gravel (no fines)
Slab isolation joint
Polyethylene vapor diffusion retarder
Perforated drain pipe located below floor slab level (piped to sump or daylight)
Granular drainage pad (coarse gravel, no fines)
Pipe connection through footing connects 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


DELTA-MS
DELTA-MS

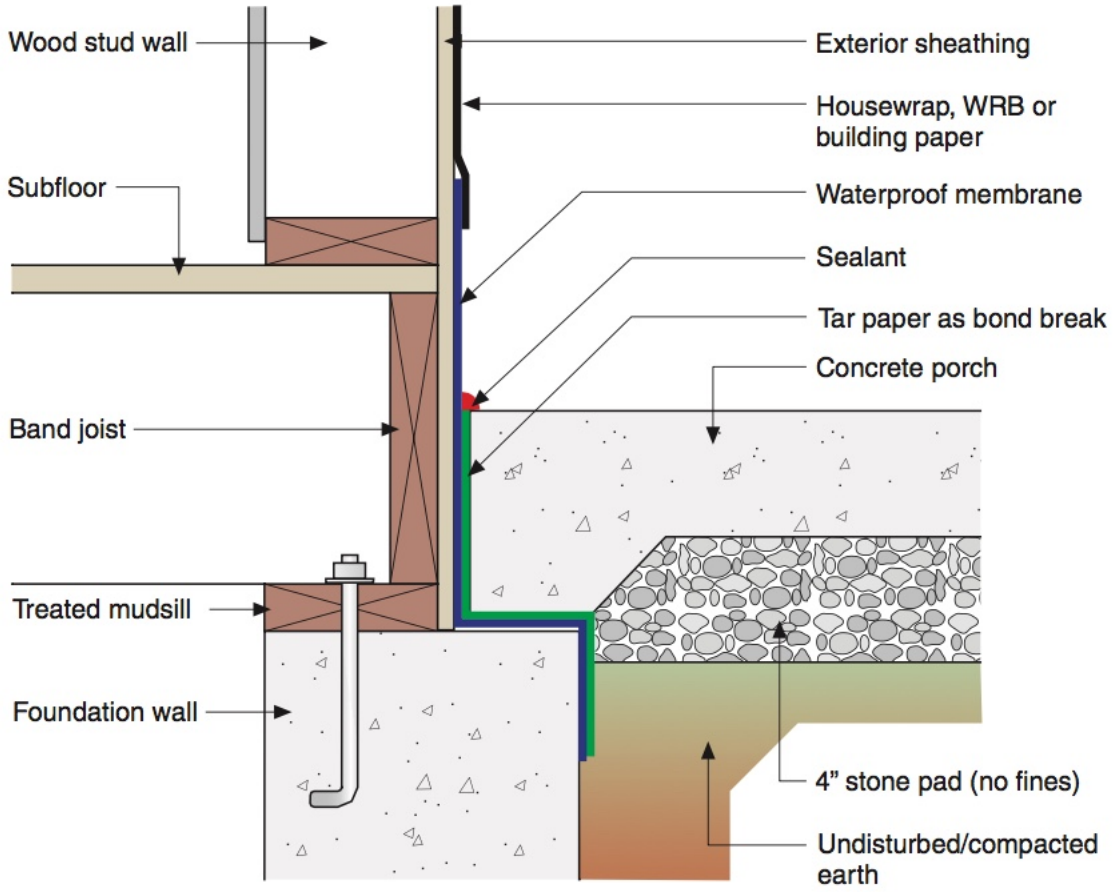

DELTA-MS
DELTA-MS


Roof flashing
Vent stack
Concrete slab
Polyethylene vapor barrier
Granular drainage pad (no fines)
Sealant at all slab penetrations
Perforated drain pipe added to "T" in order to couple sub-slab pressure field to vent stack

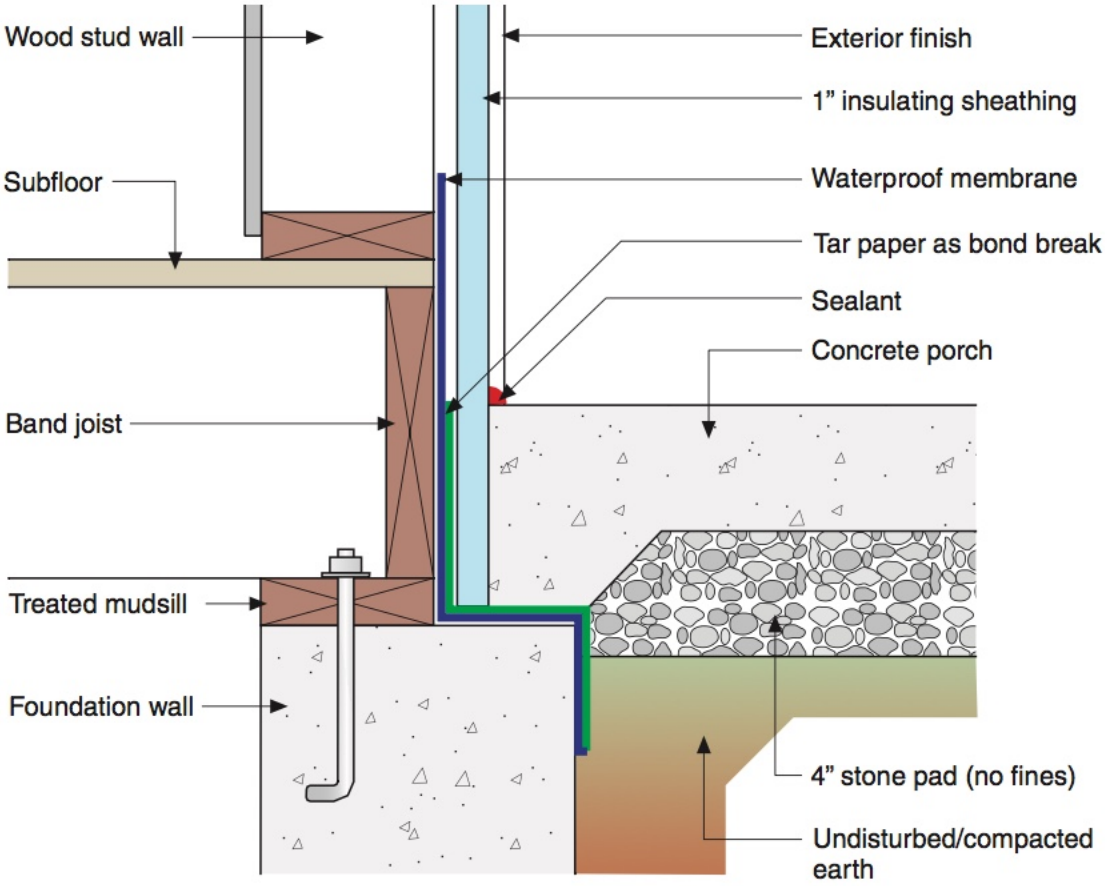

Roof flashing
Vent stack
Continuous polyethylene vapor barrier/air barrier (all joints taped)
Polyethylene mechanically attached to foundation wall perimeter and sealed
Perforated drain pipe trench covered with course gravel (no fines)
Sealant at all penetrations in air barrier
Perforated drain pipe at perimeter connected to vent stack


Roof flashing
Vent stack
Polyethylene
vapor barrier
Concrete slab
Sealant at all
penetrations in
air barrier
Perforated drain pipe added
to "T" in order to couple sub-
slab pressure field to vent stack

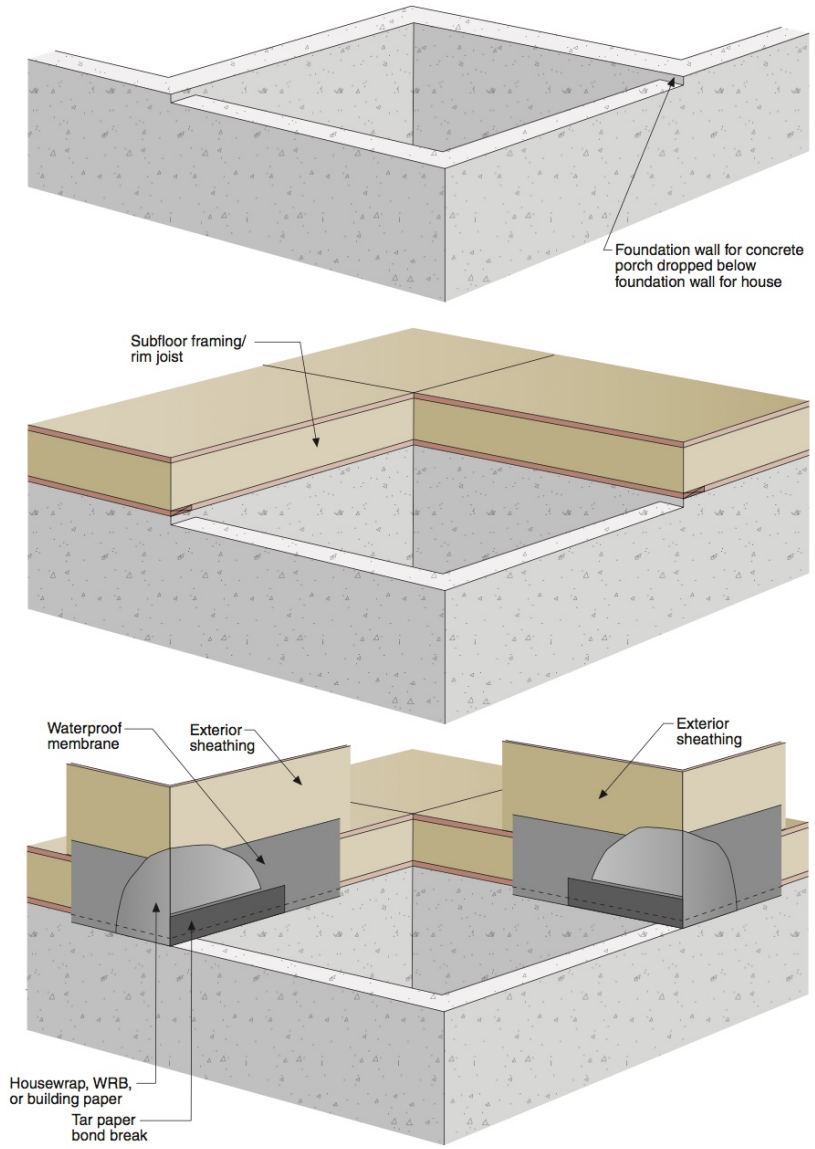
Concrete Porch Slab with Housewrap

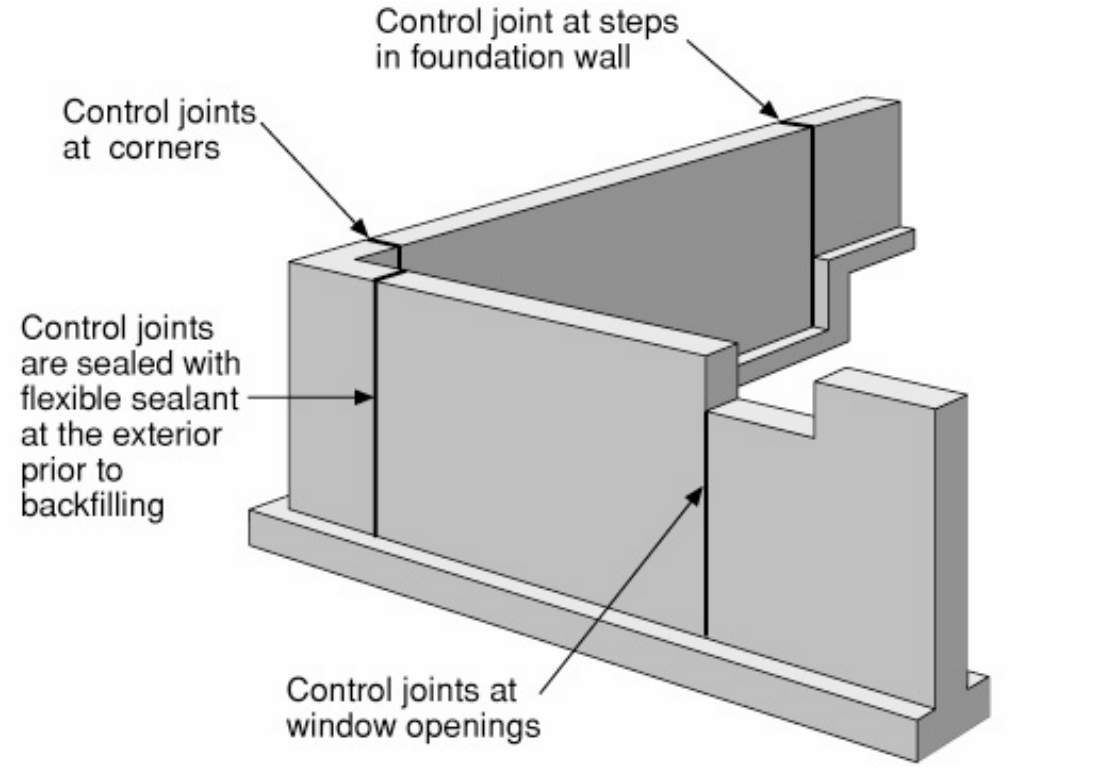


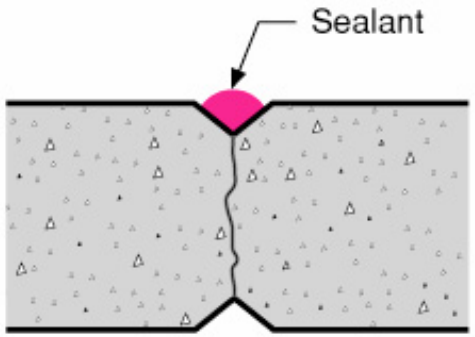
Concrete Porch Slab with Insulating Sheathing



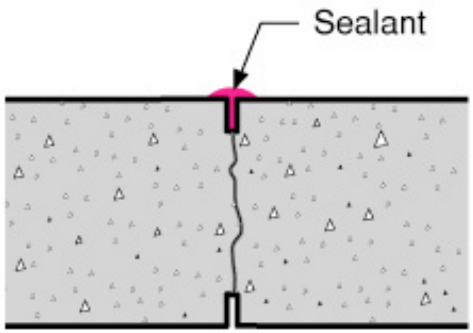
Concrete Porch/Foundation Intersection



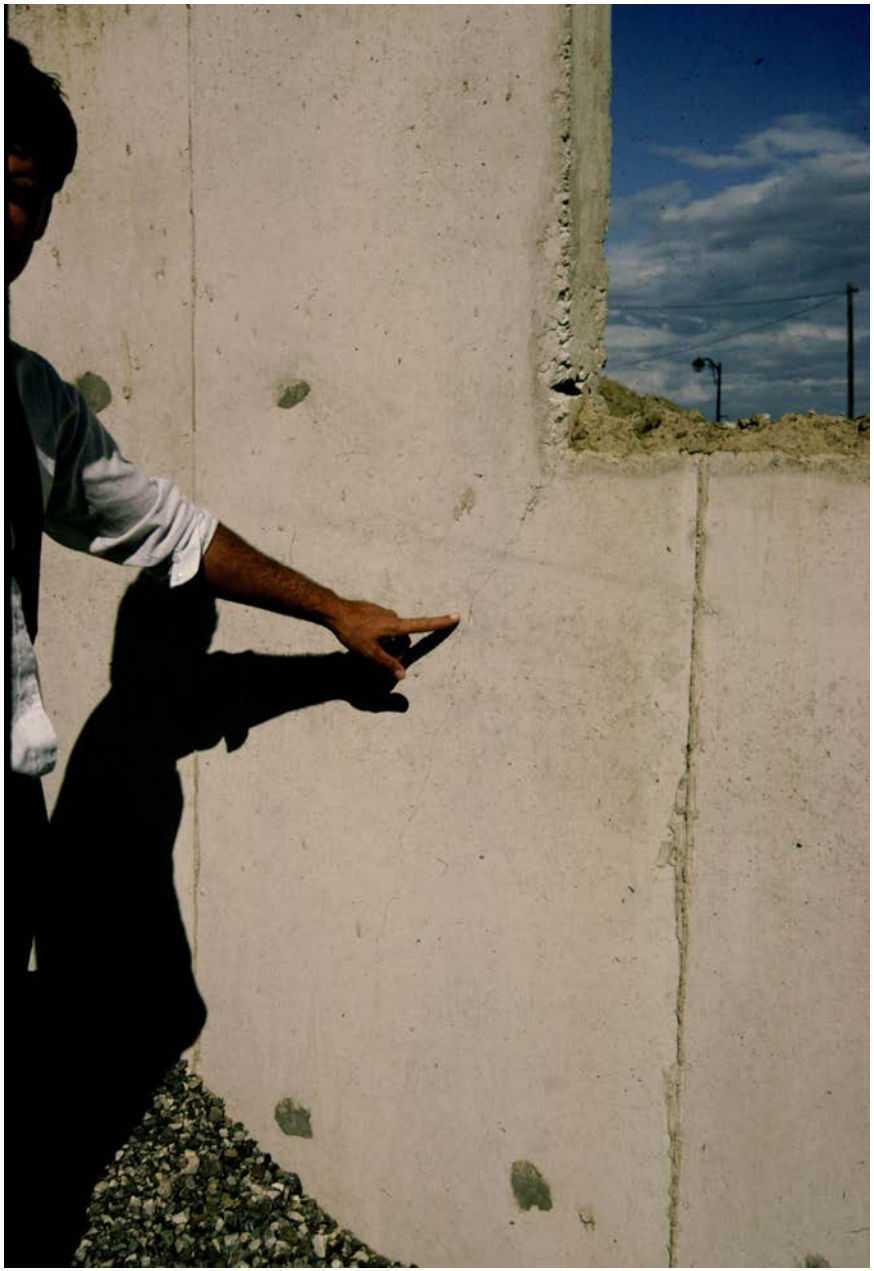


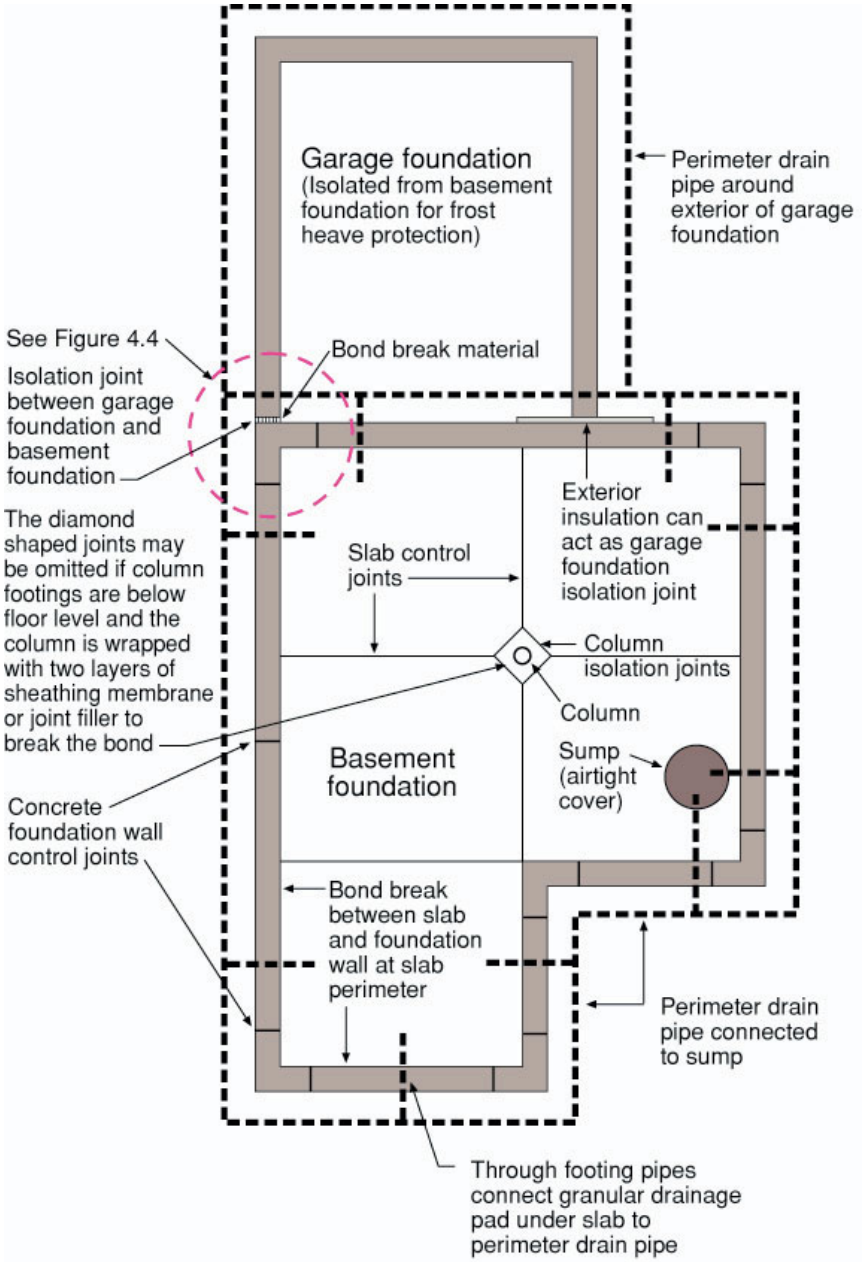


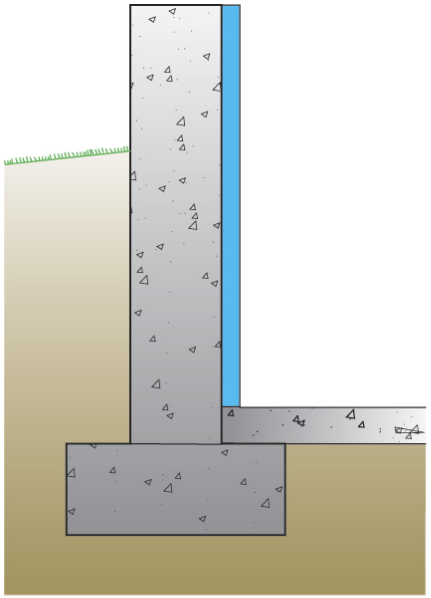
Diagonally cut 2 x 2's in forms provide goose neck joint



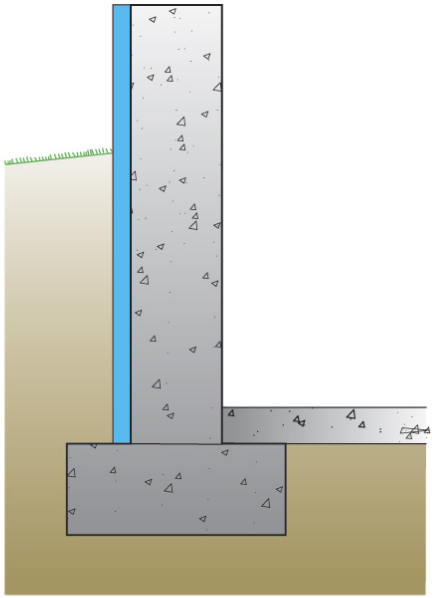
Saw cut joint



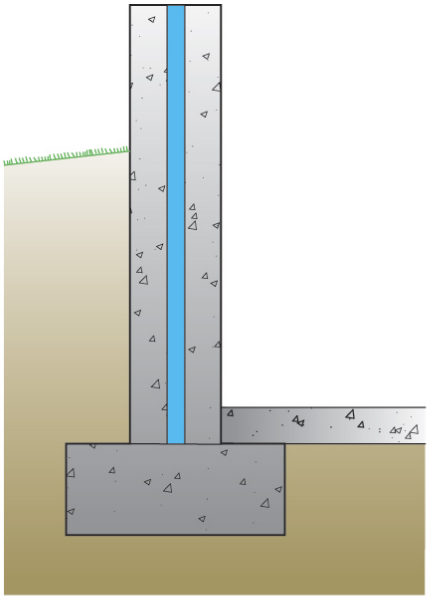

Garage foundation
(Isolated from basement foundation for frost heave protection)
Perimeter drain pipe around exterior of garage foundation
See Figure 4.4
Isolation joint between garage foundation and basement foundation
Bond break material
The diamond shaped joints may be omitted if column footings are below floor level and the column is wrapped with two layers of sheathing membrane or joint filler to break the bond
Slab control joints
Exterior insulation can act as garage foundation isolation joint
Column isolation joints
Column
Basement foundation
Sump (airtight cover)
Concrete foundation wall control joints
Bond break between slab and foundation wall at slab perimeter
Perimeter drain pipe connected to sump
Through footing pipes connect granular drainage pad under slab to perimeter drain pipe



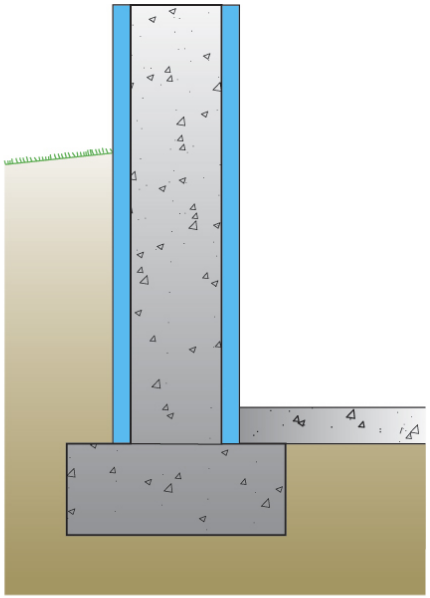
Internally Insulated Basement



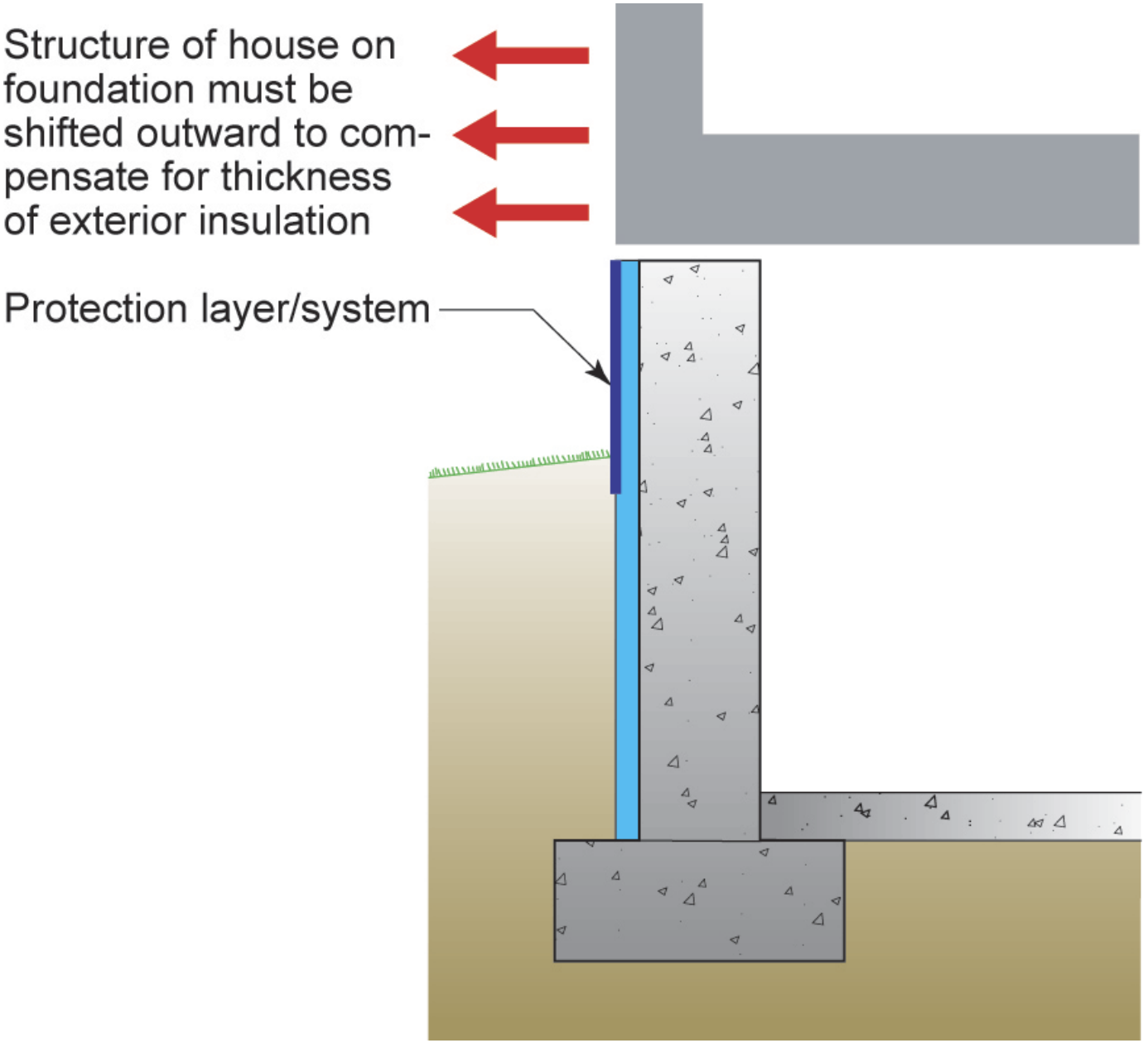
Externally Insulated Basement



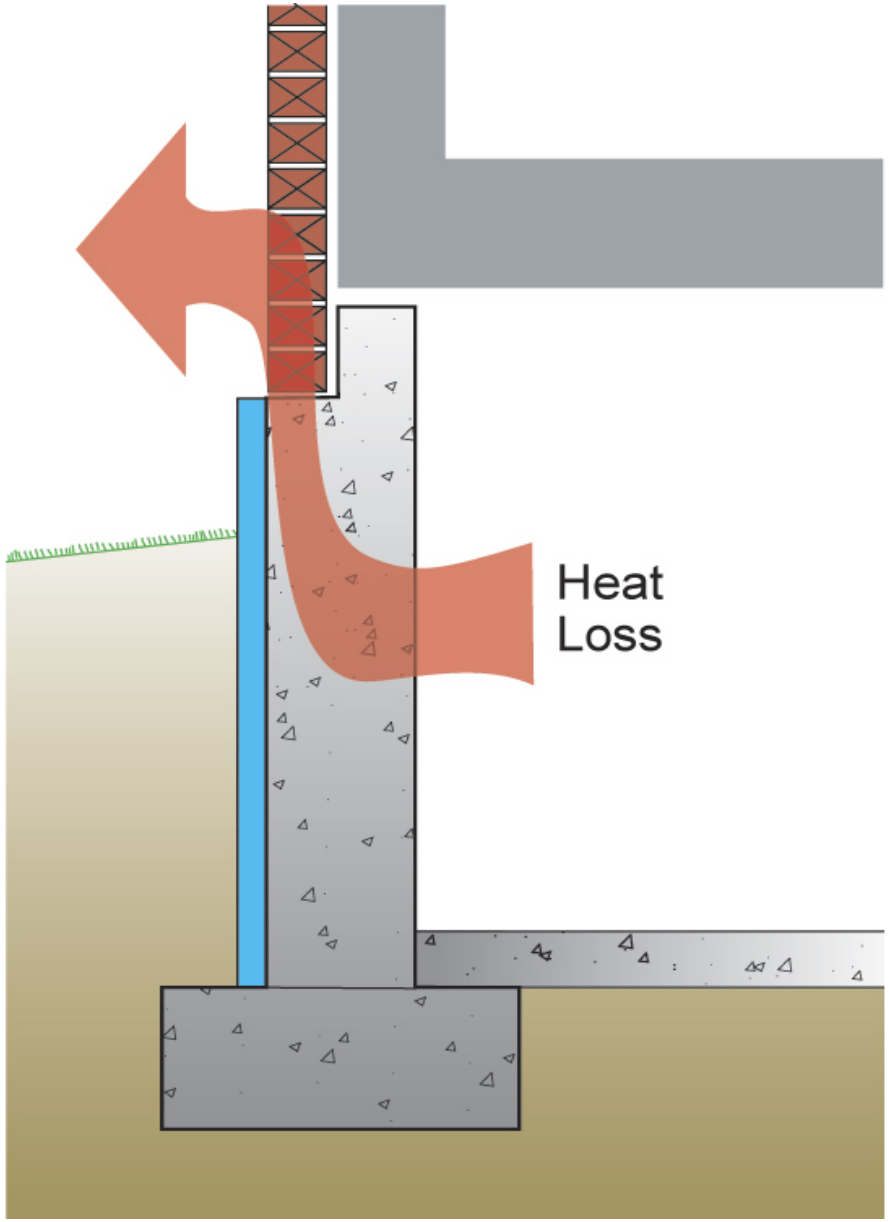
Basement Insulated in the Middle

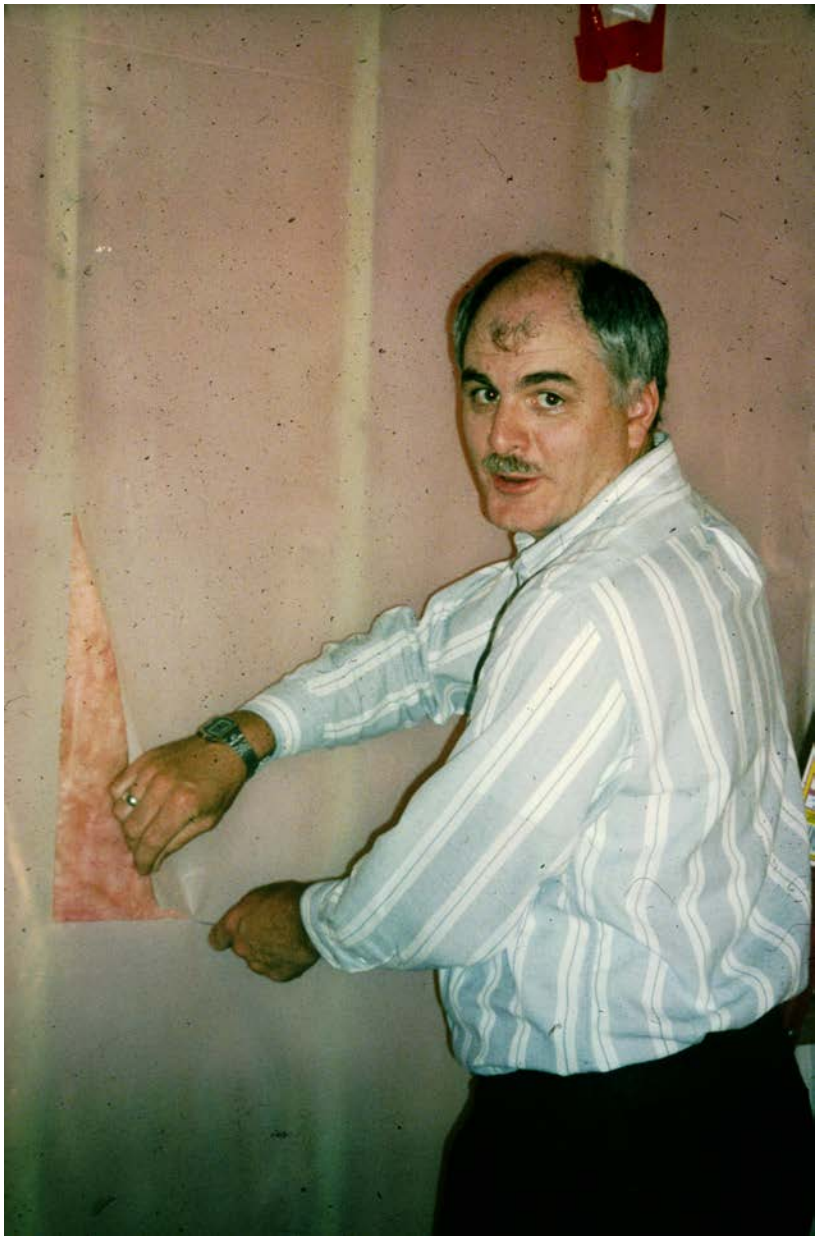


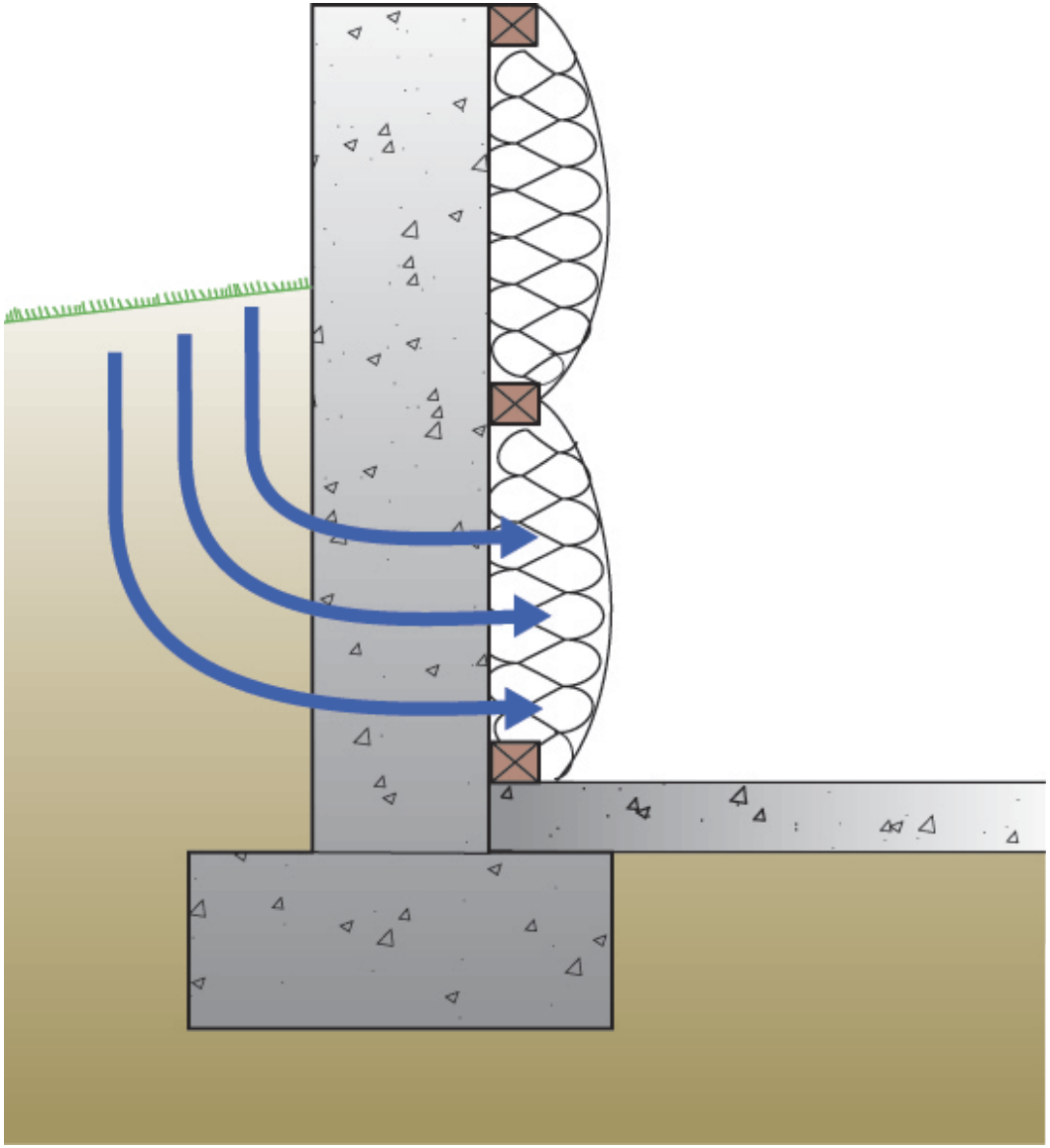
Basement Insulated Both Externally and Internally

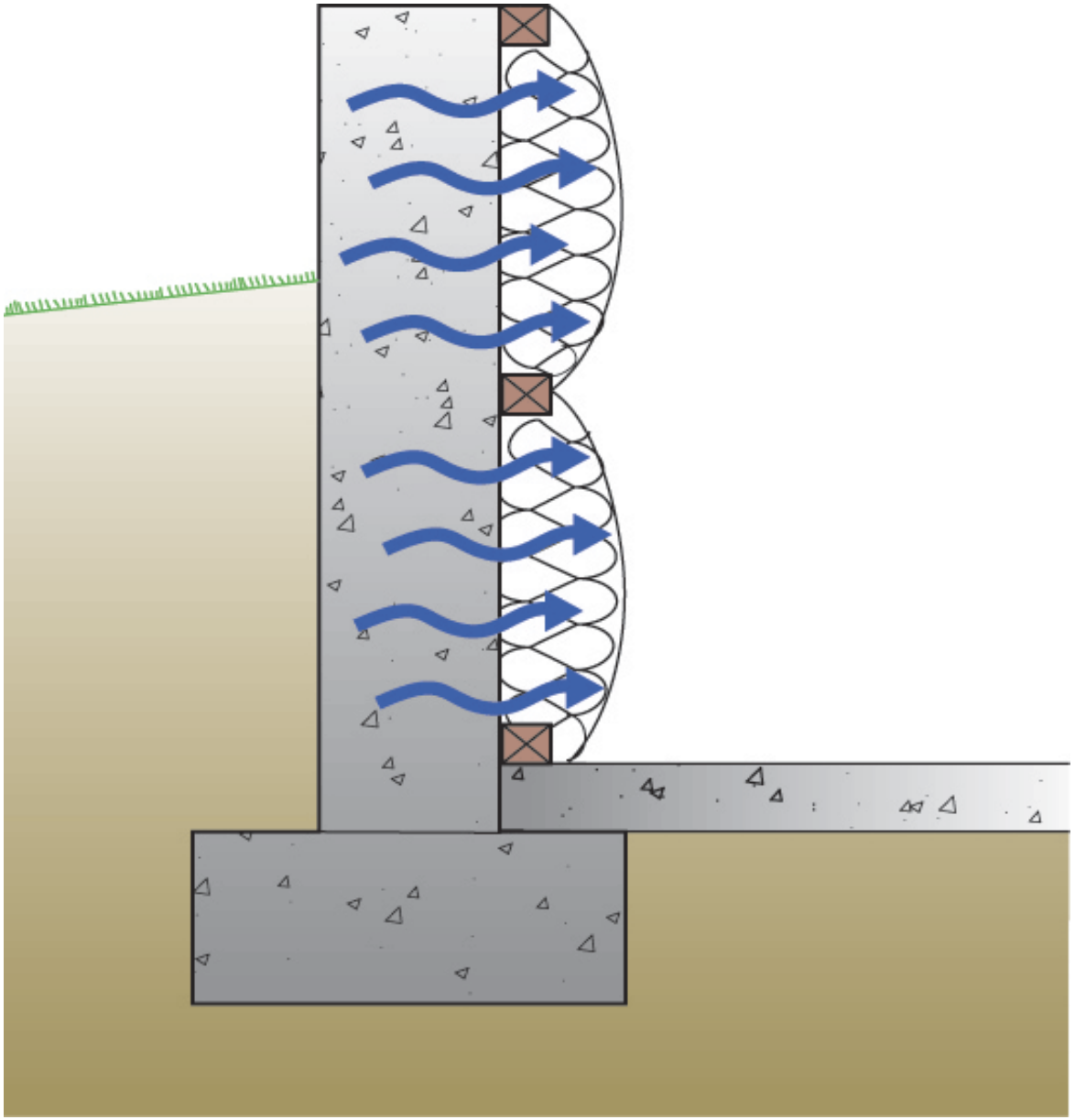

Structure of house on foundation must be shifted outward to compensate for thickness of exterior insulation
Protection layer/system

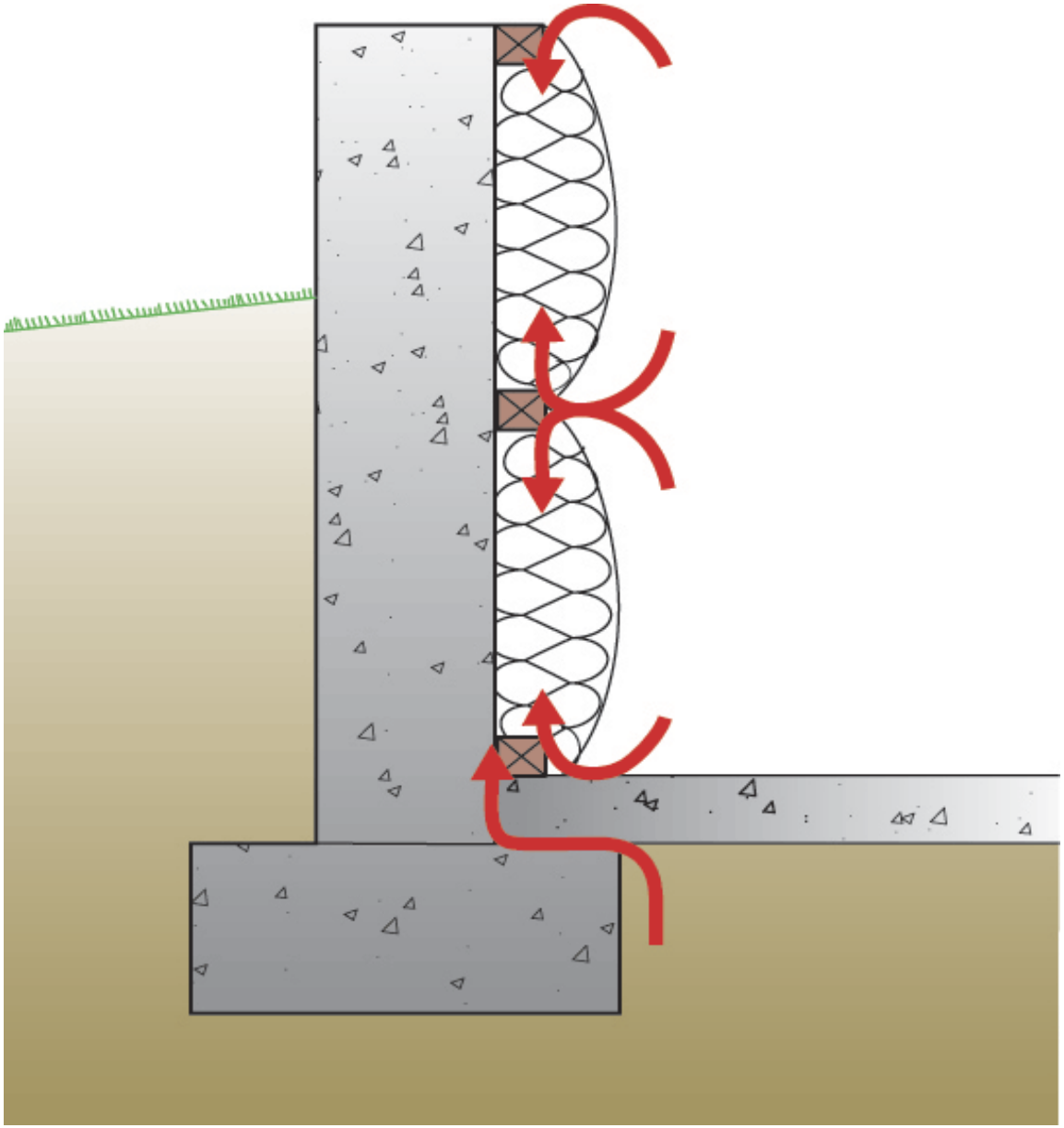

STYROFOAM
Foundation
Coating Kit
27

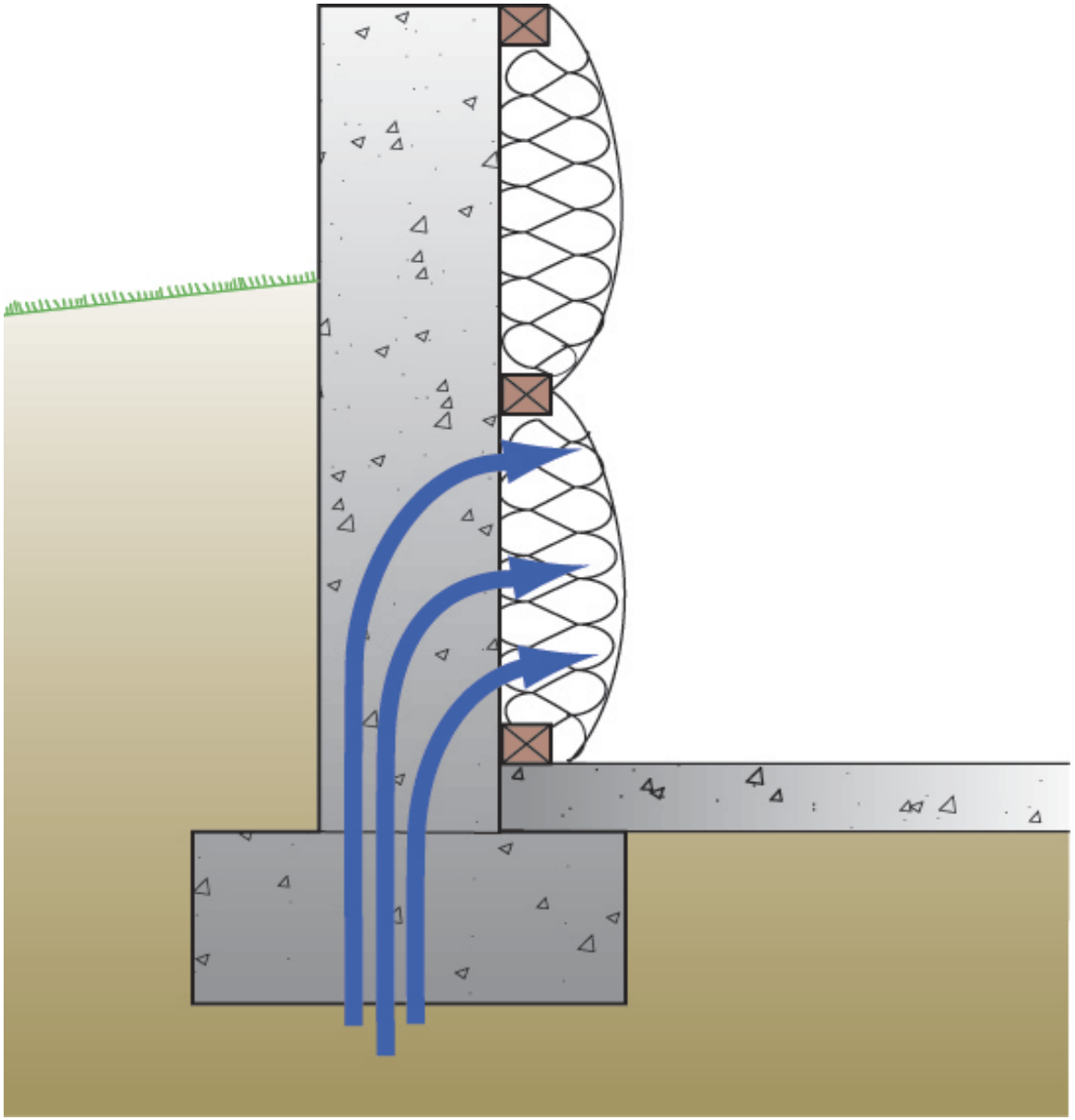

Heat
Loss



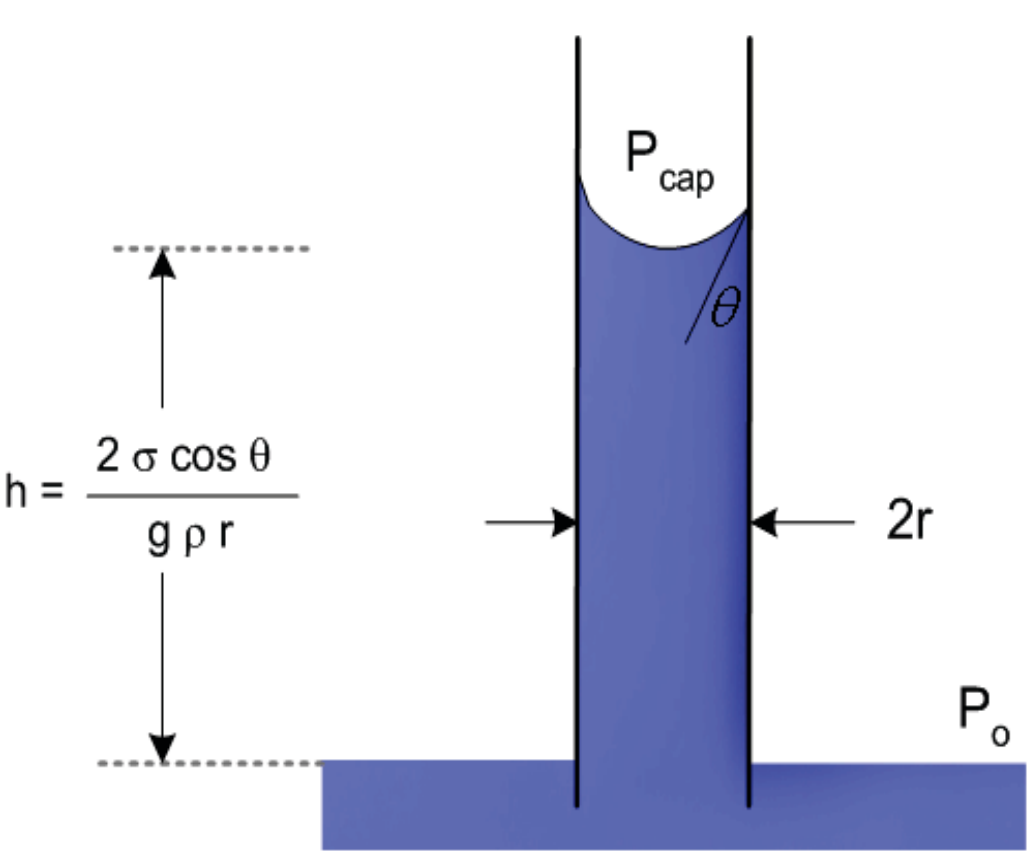


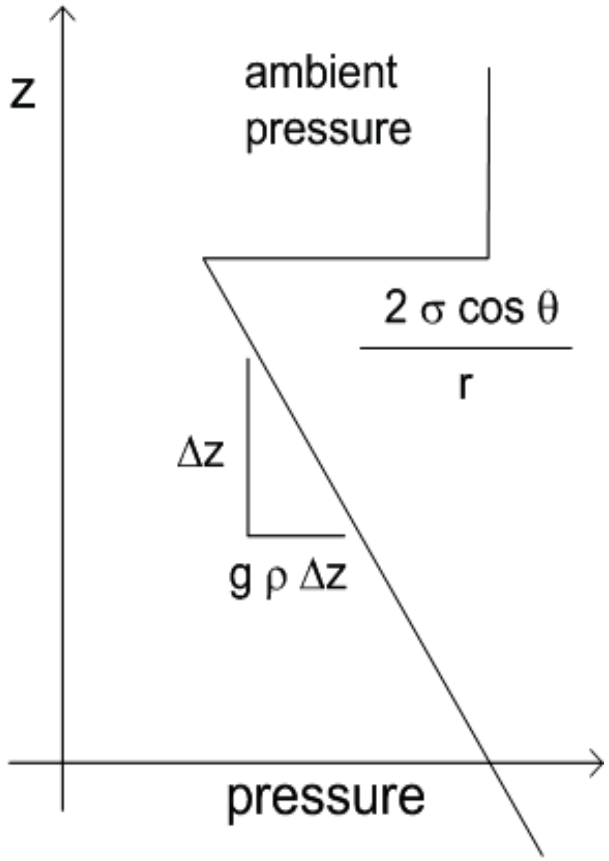




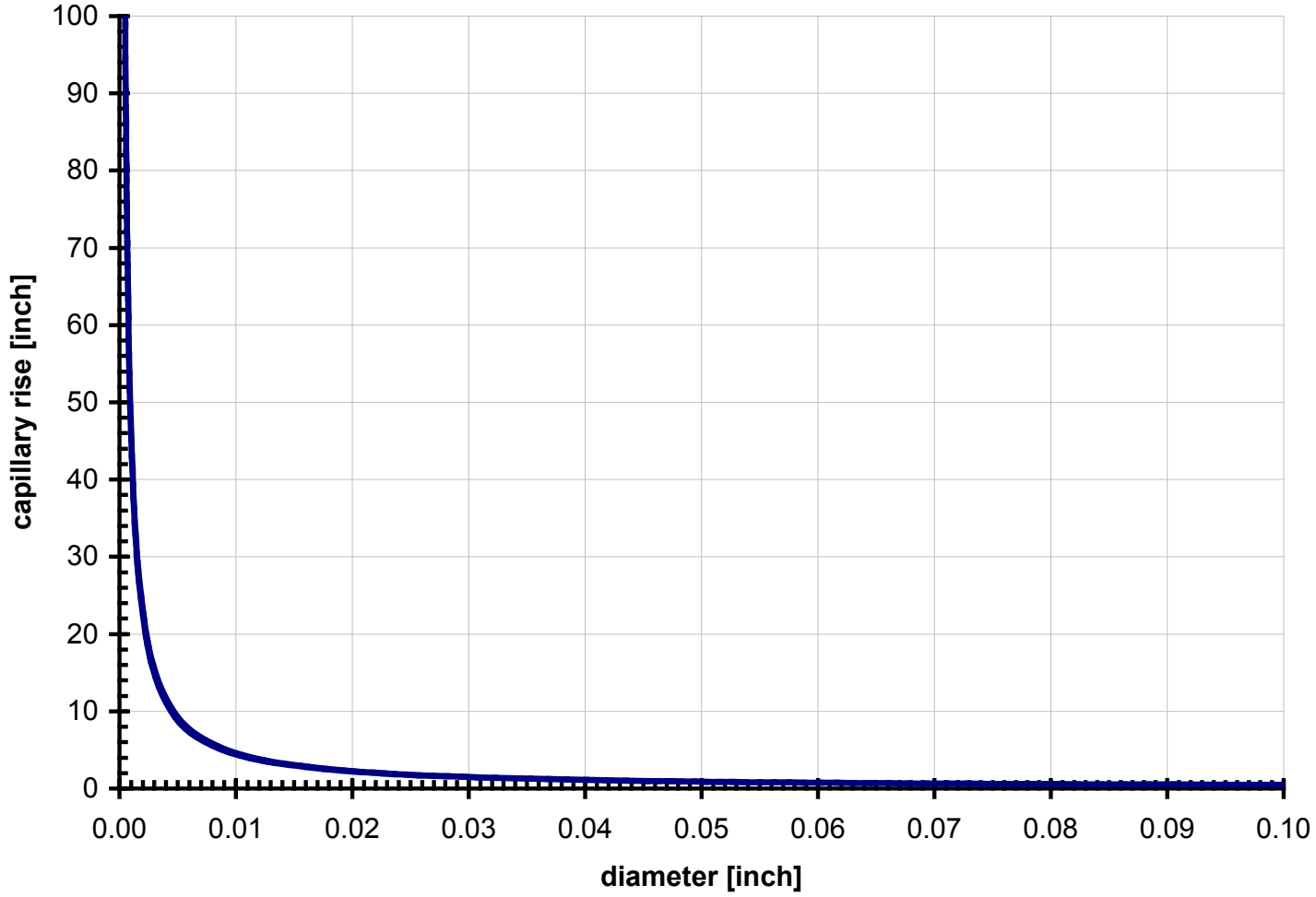


Calculating capillary rise



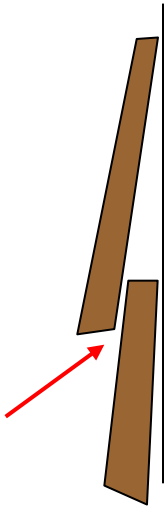


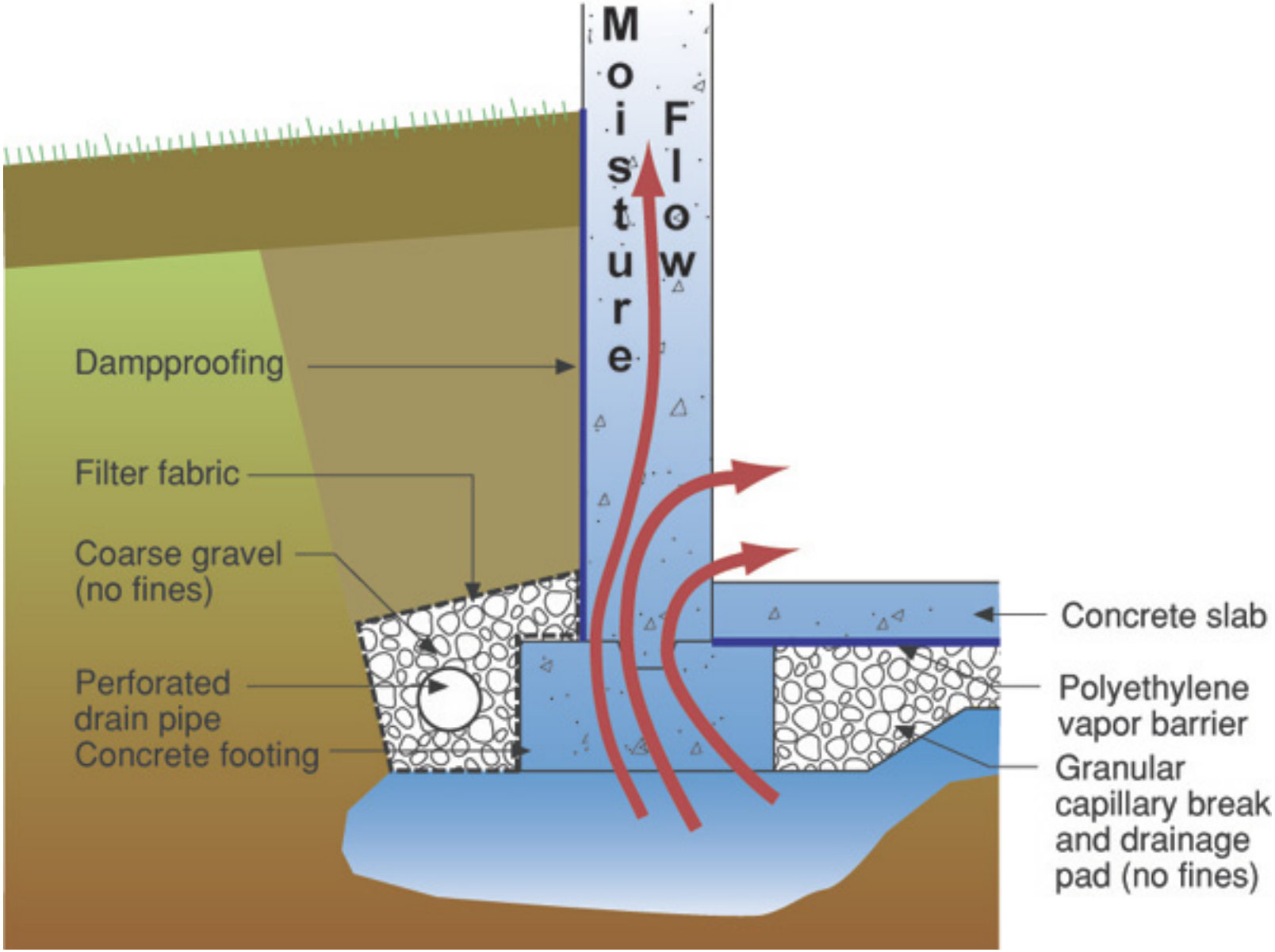
Capillary rise versus diameter

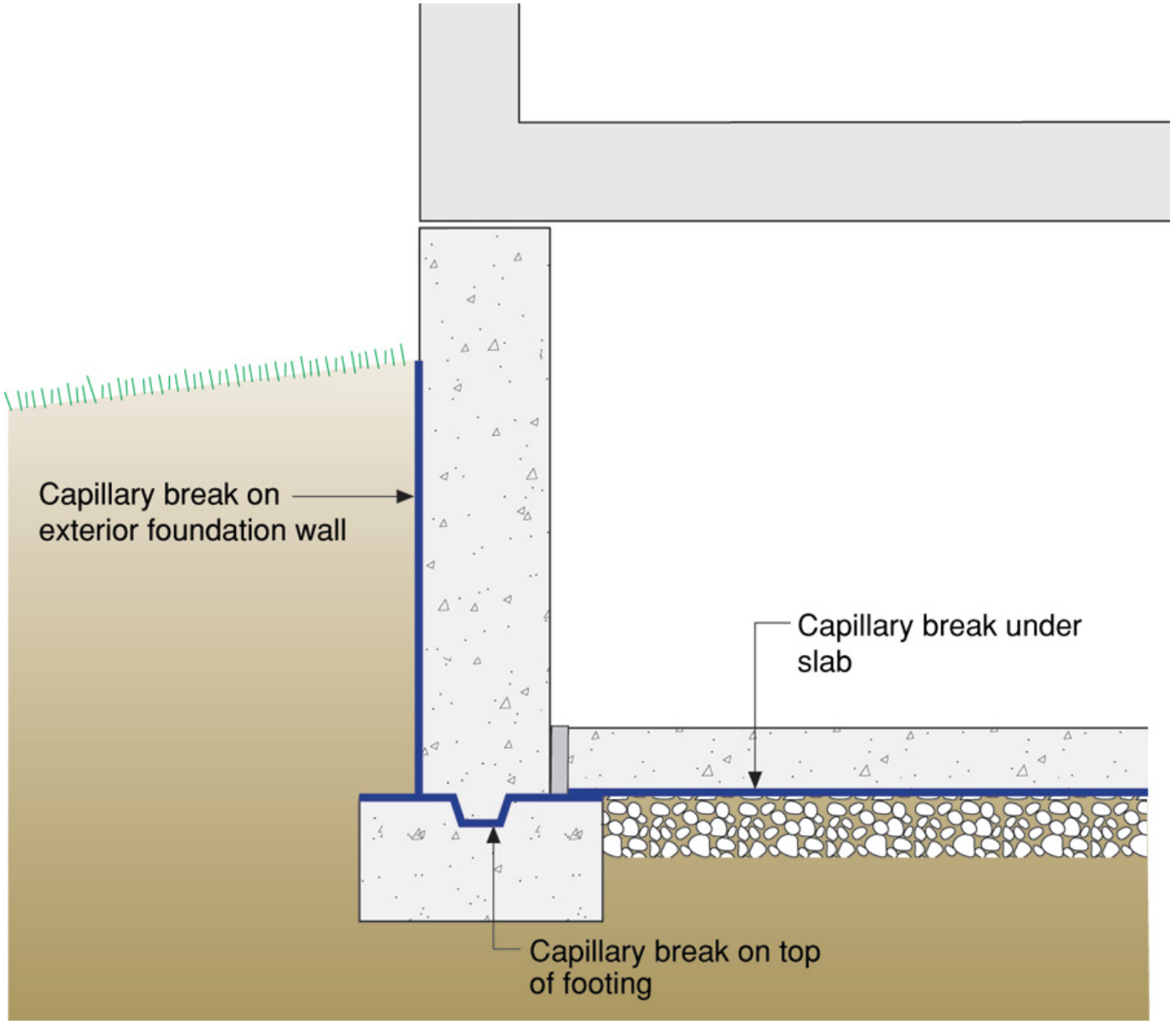


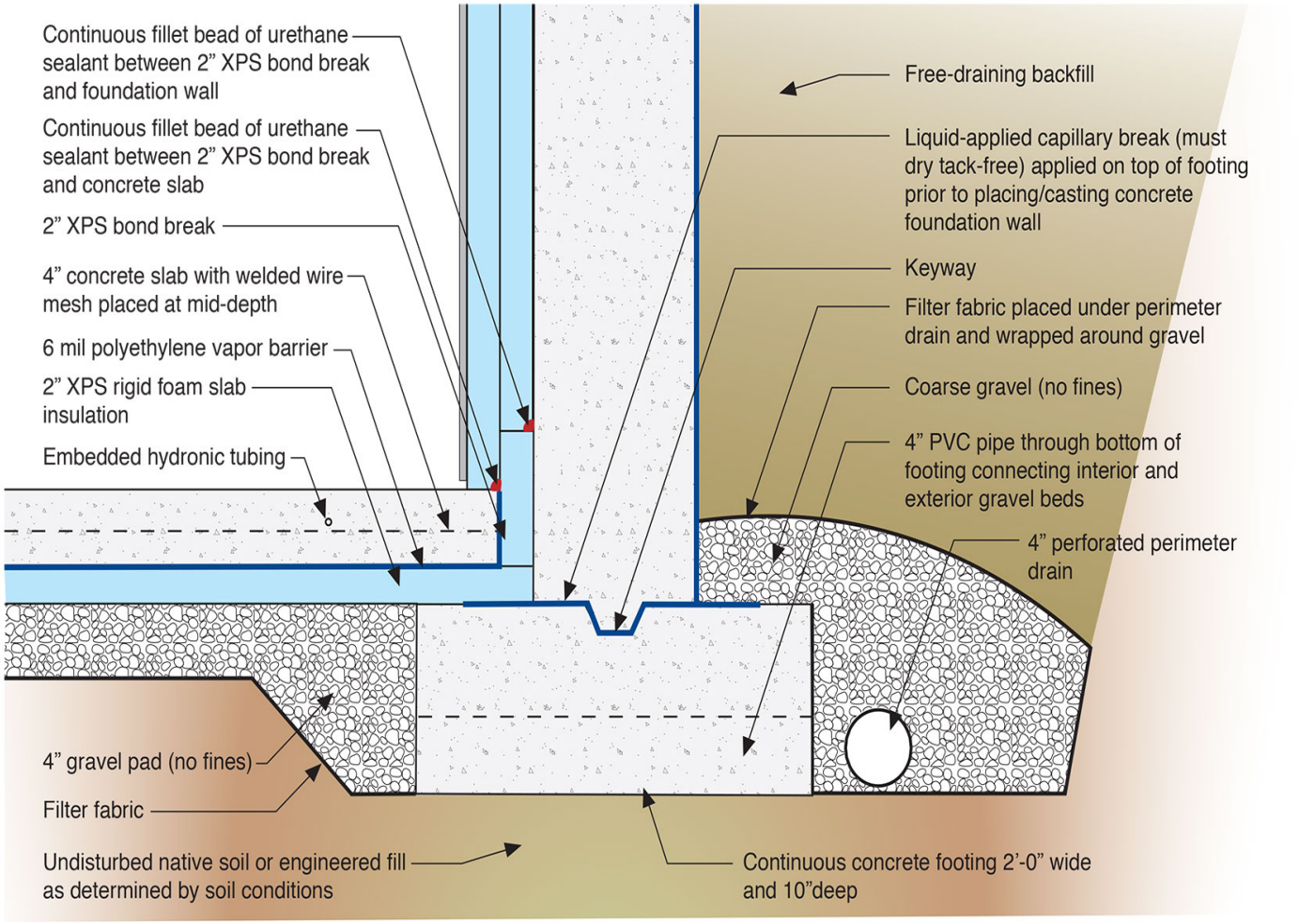
Capillary Flow

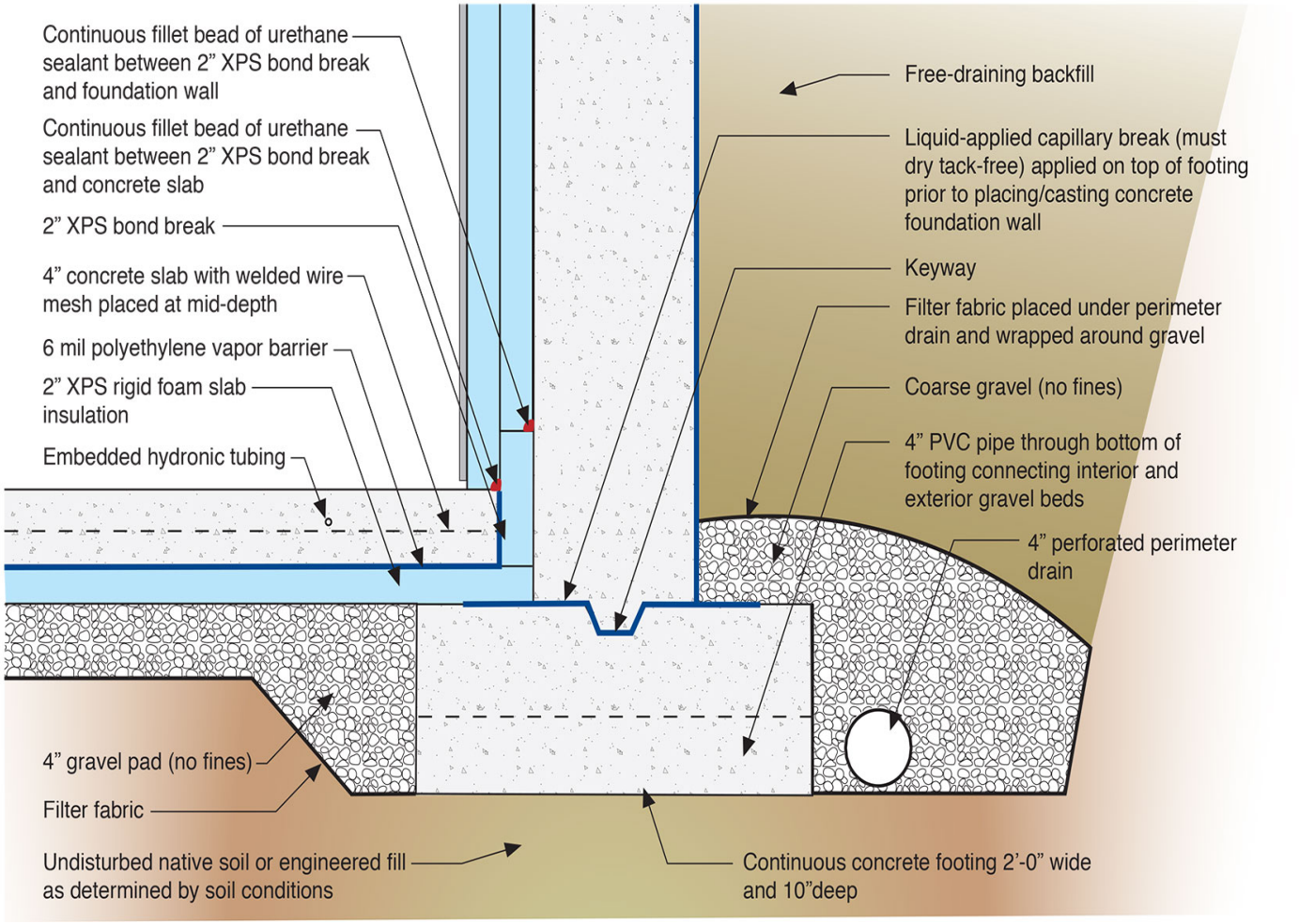
Siding laps

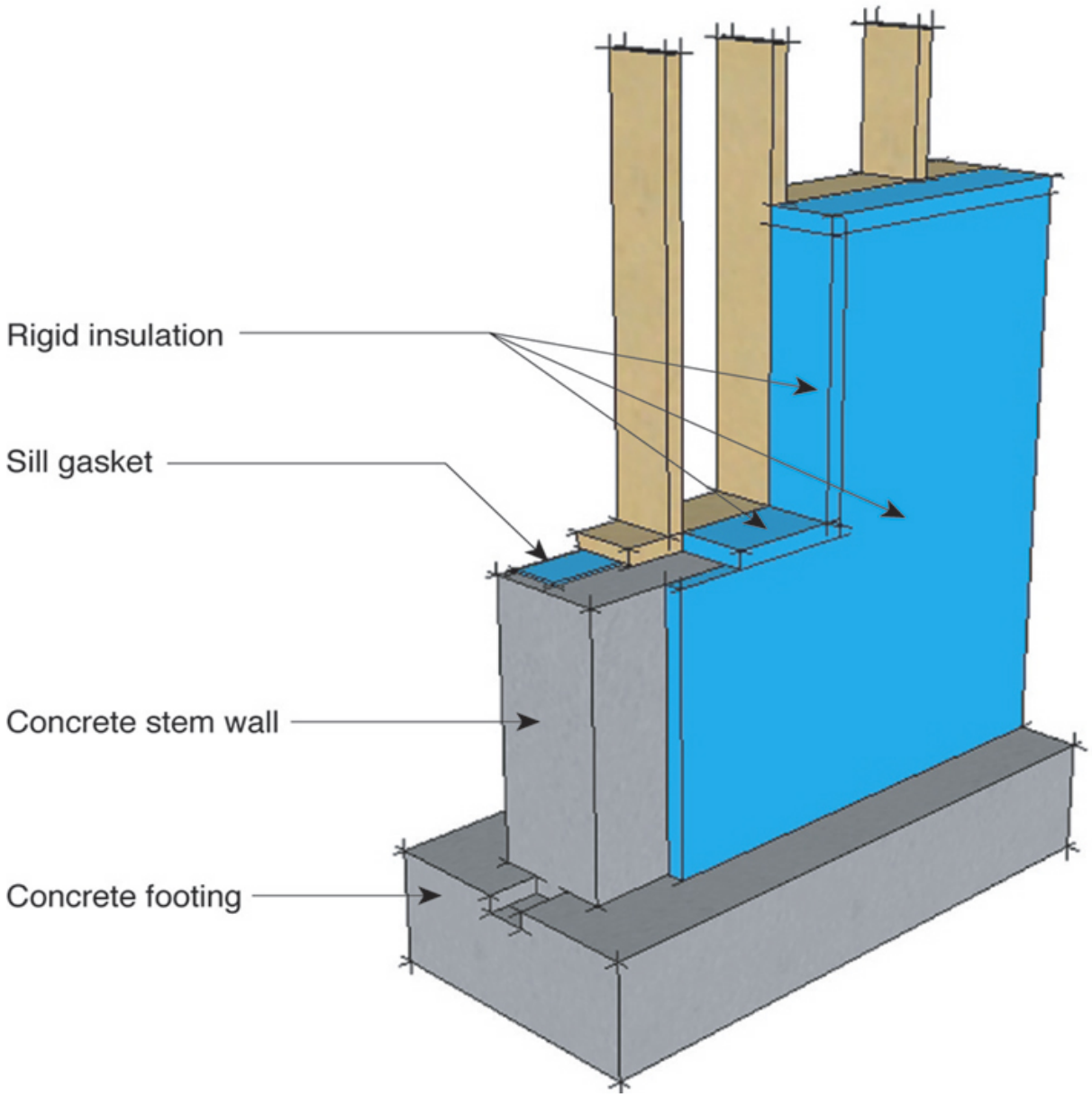


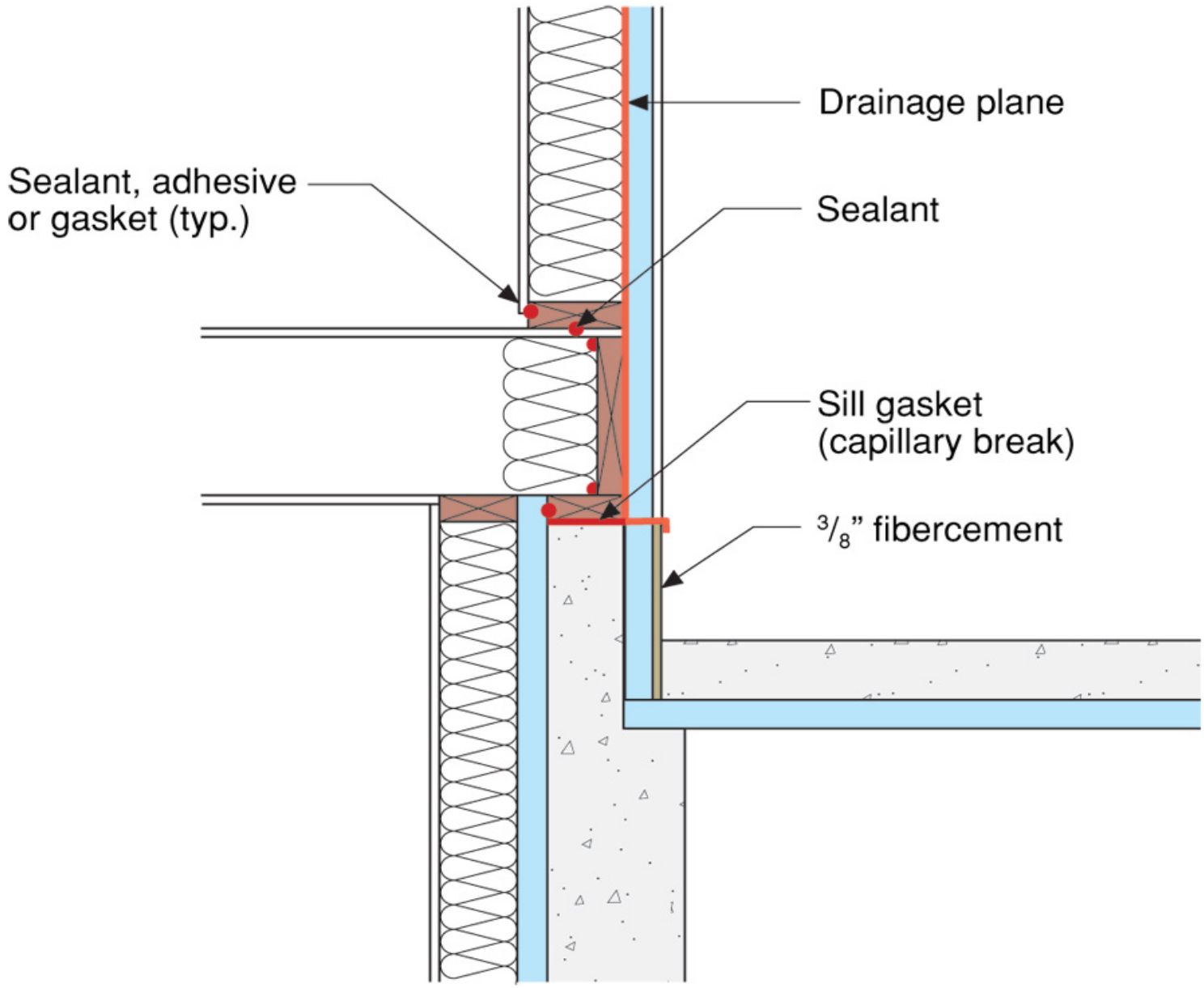

Moisture Flow
Dampproofing
Filter fabric
Coarse gravel
(no fines)
Perforated
drain pipe
Concrete footing
Concrete slab
Polyethylene
vapor barrier
Granular
capillary break
and drainage
pad (no fines)

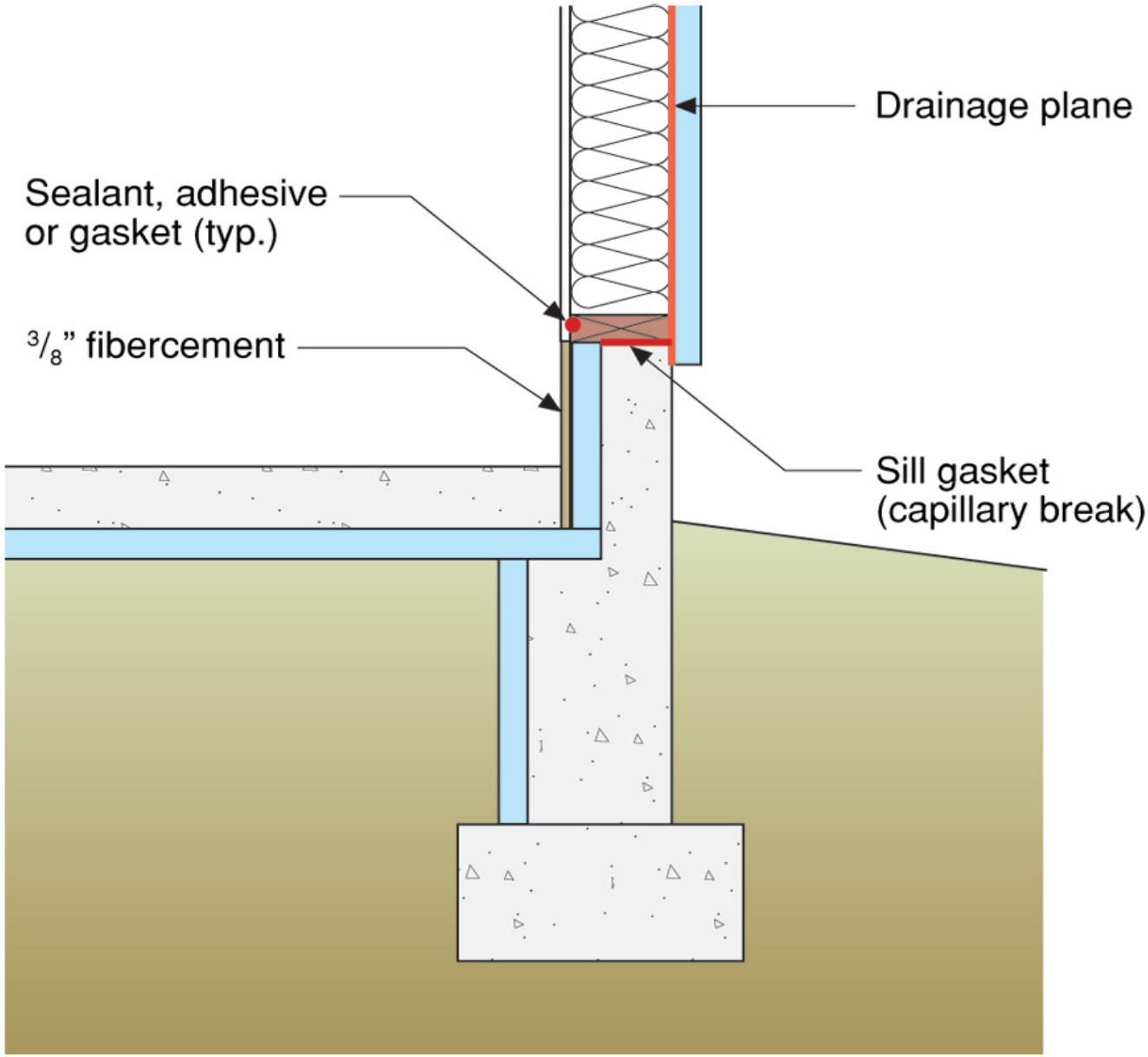

Capillary break on
exterior foundation wall
Capillary break under
slab
Capillary break on top
of footing

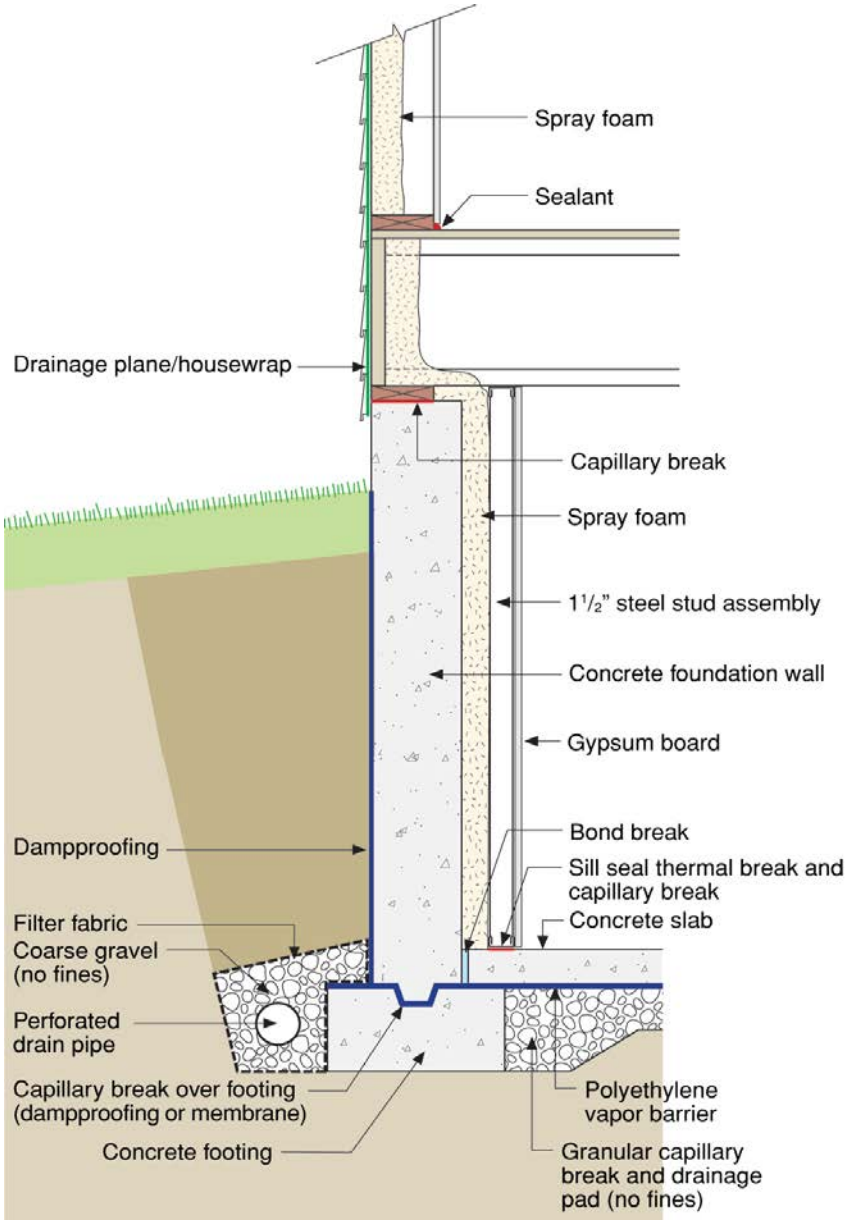

Continuous fillet bead of urethane sealant between 2” XPS bond break and foundation wall
Continuous fillet bead of urethane sealant between 2” XPS bond break and concrete slab
2” XPS bond break
4” concrete slab with welded wire mesh placed at mid-depth
6 mil polyethylene vapor barrier
2” XPS rigid foam slab insulation
Embedded hydronic tubing
4” gravel pad (no fines)
Filter fabric
Undisturbed native soil or engineered fill as determined by soil conditions
Free-draining backfill
Liquid-applied capillary break (must dry tack-free) applied on top of footing prior to placing/casting concrete foundation wall
Keyway
Filter fabric placed under perimeter drain and wrapped around gravel
Coarse gravel (no fines)
4” PVC pipe through bottom of footing connecting interior and exterior gravel beds
4” perforated perimeter drain
Continuous concrete footing 2’-0” wide and 10”deep

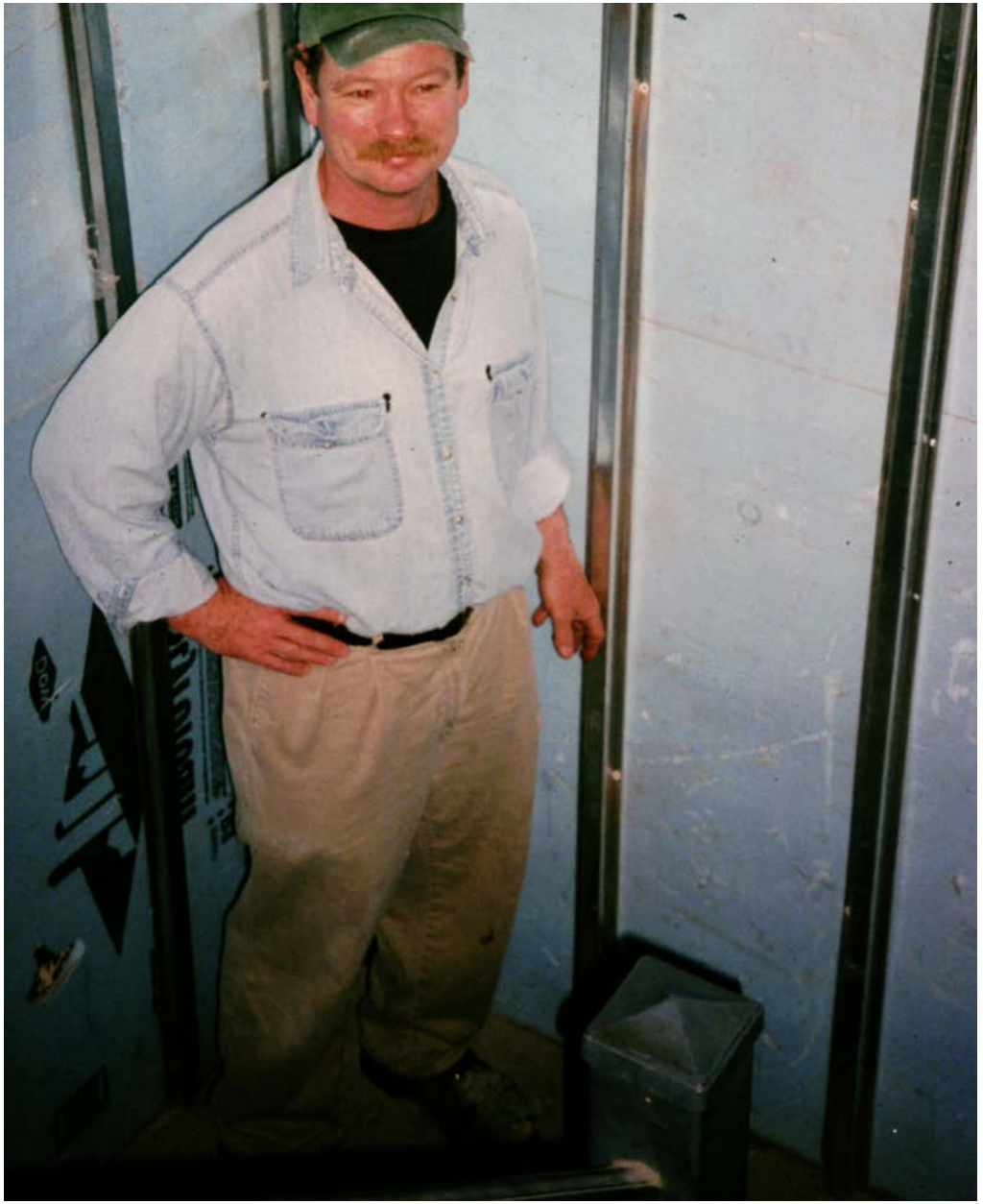

Continuous fillet bead of urethane sealant between 2” XPS bond break and foundation wall
Continuous fillet bead of urethane sealant between 2” XPS bond break and concrete slab
2” XPS bond break
4” concrete slab with welded wire mesh placed at mid-depth
6 mil polyethylene vapor barrier
2” XPS rigid foam slab insulation
Embedded hydronic tubing
4” gravel pad (no fines)
Filter fabric
Undisturbed native soil or engineered fill as determined by soil conditions
Free-draining backfill
Liquid-applied capillary break (must dry tack-free) applied on top of footing prior to placing/casting concrete foundation wall
Keyway
Filter fabric placed under perimeter drain and wrapped around gravel
Coarse gravel (no fines)
4” PVC pipe through bottom of footing connecting interior and exterior gravel beds
4” perforated perimeter drain
Continuous concrete footing 2’-0” wide and 10”deep

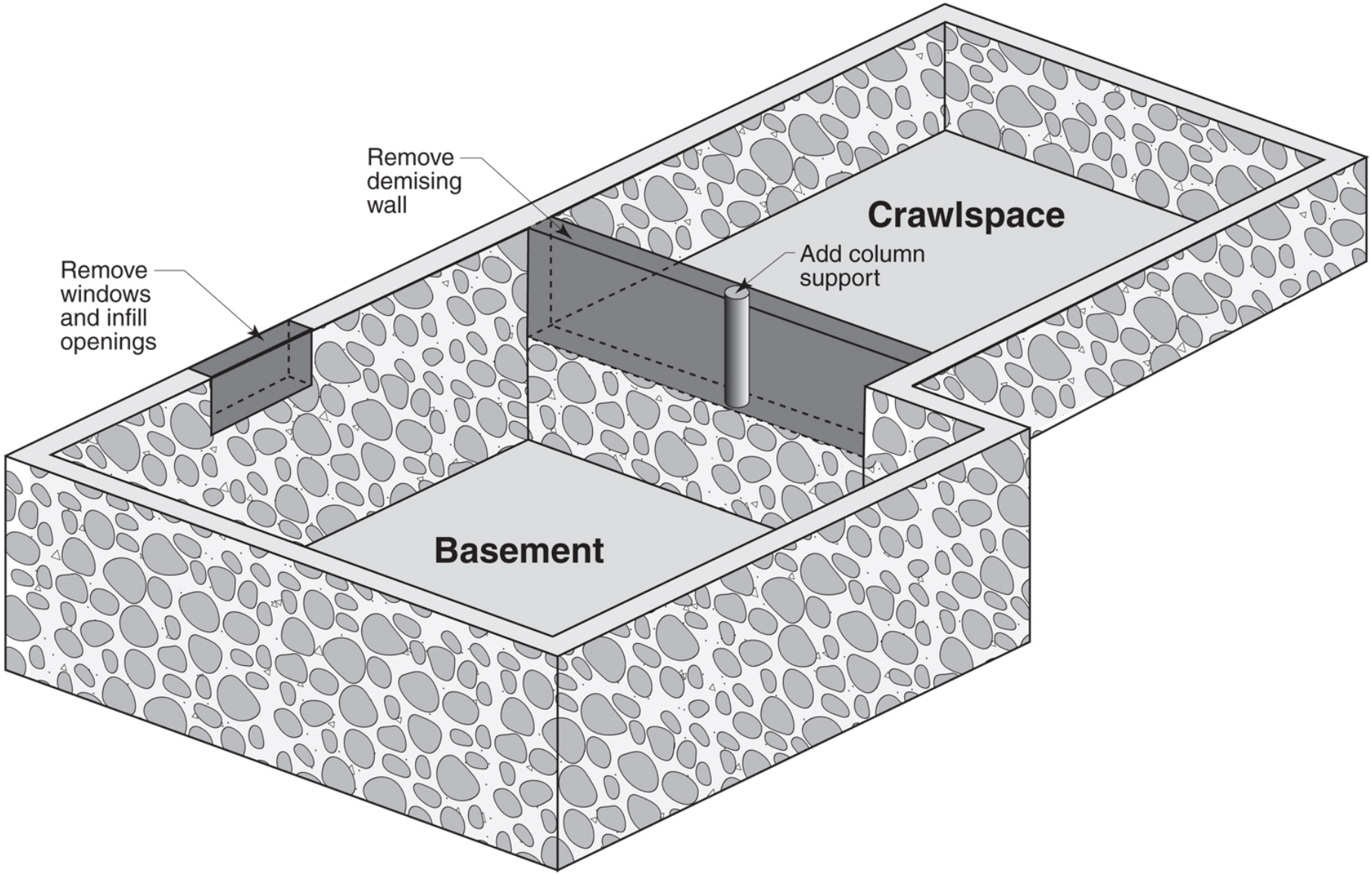

Rigid insulation
Sill gasket
Concrete stem wall
Concrete footing

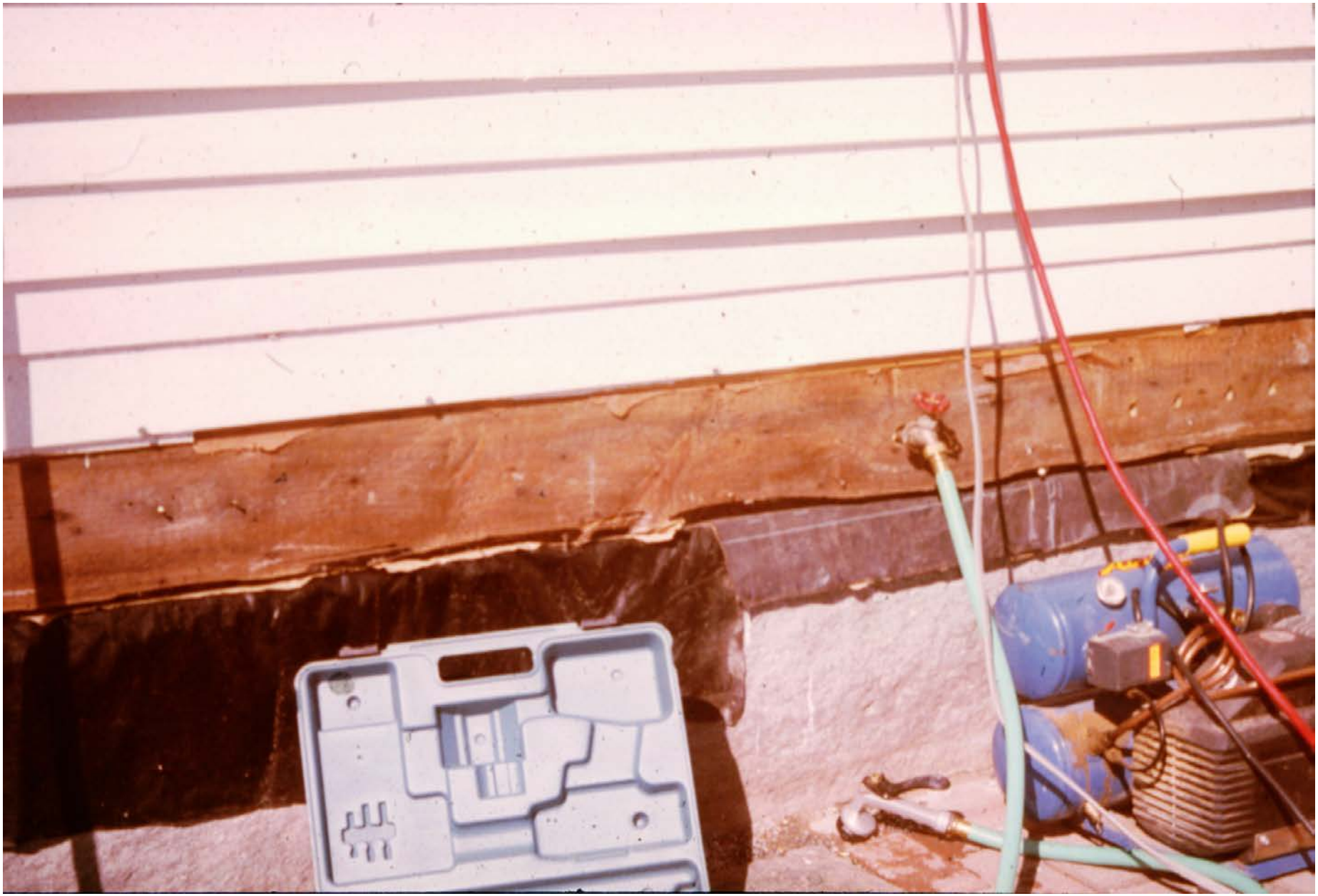

Drainage plane
Sealant, adhesive
or gasket (typ.)
Sealant
Sill gasket
(capillary break)
3/8" fibercement

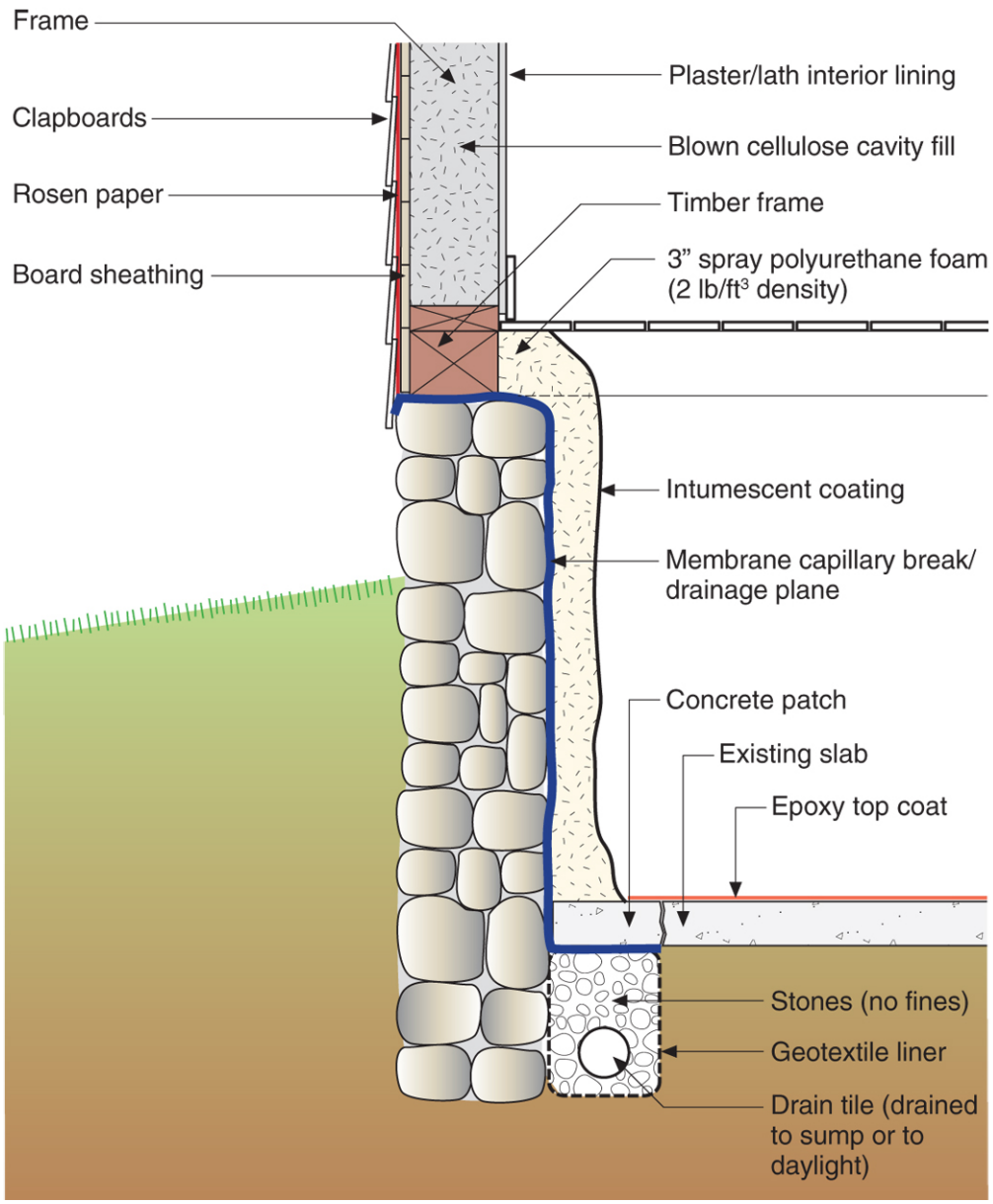

Drainage plane
Sealant, adhesive or gasket (typ.)
3/8" fibercement
Sill gasket (capillary break)


Spray foam
Sealant
Drainage plane/housewrap
Capillary break
Spray foam
1½" steel stud assembly
Concrete foundation wall
Gypsum board
Bond break
Sill seal thermal break and capillary break
Concrete slab
Dampproofing
Filter fabric
Coarse gravel (no fines)
Perforated drain pipe
Capillary break over footing (dampproofing or membrane)
Concrete footing
Polyethylene vapor barrier
Granular capillary break and drainage pad (no fines)

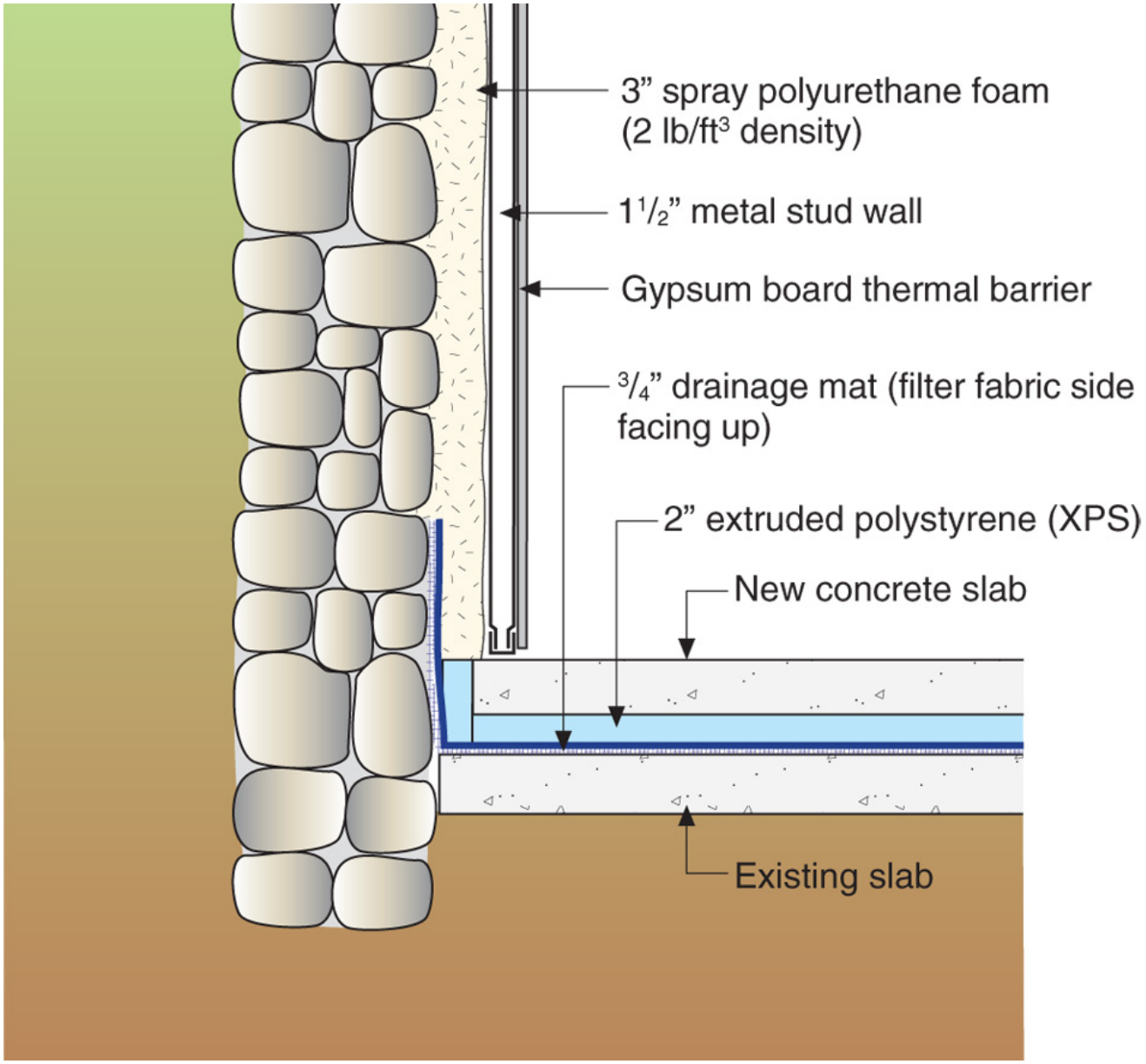


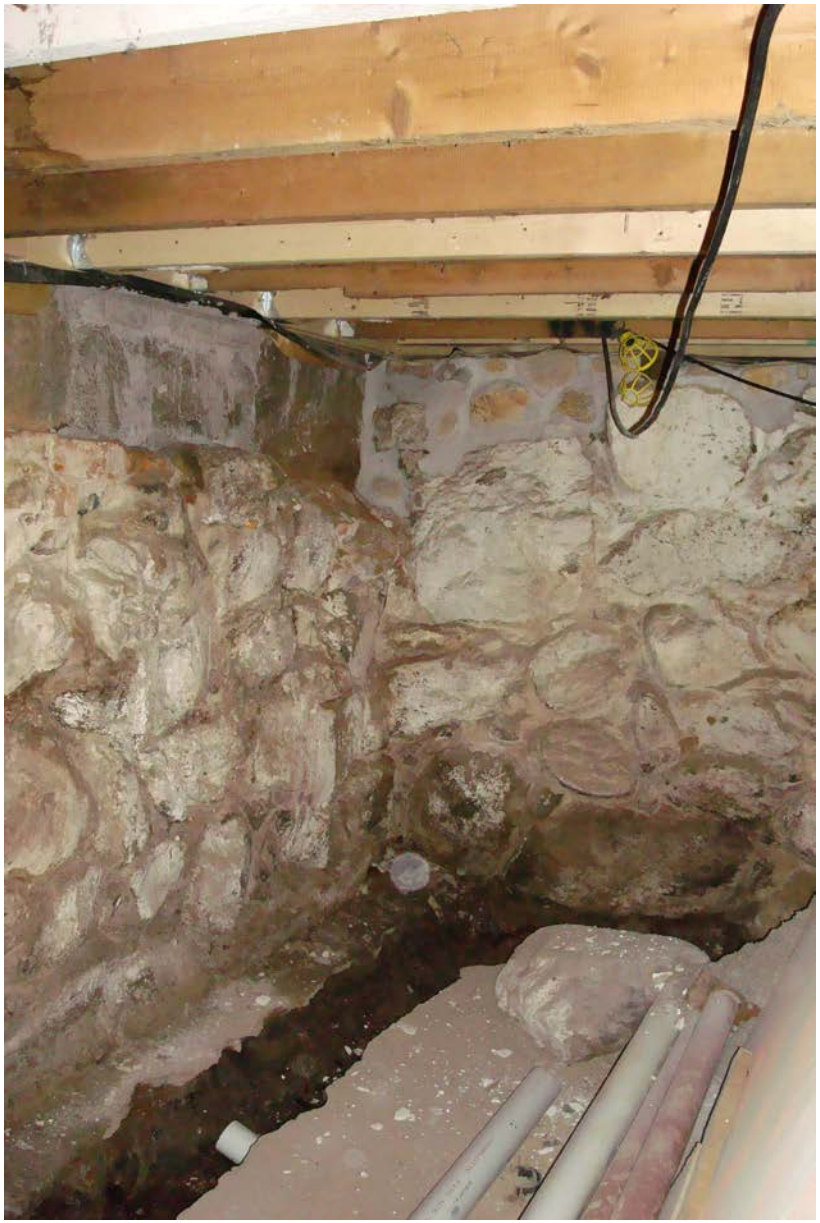

Remove
demising
wall
Crawlspace
Add column
support
Remove
windows
and infill
openings
Basement




Frame
Clapboards
Rosen paper
Board sheathing
Plaster/lath interior lining
Blown cellulose cavity fill
Timber frame
3” spray polyurethane foam
(2 lb/ft³ density)
Intumescent coating
Membrane capillary break/
drainage plane
Concrete patch
Existing slab
Epoxy top coat
Stones (no fines)
Geotextile liner
Drain tile (drained
to sump or to
daylight)

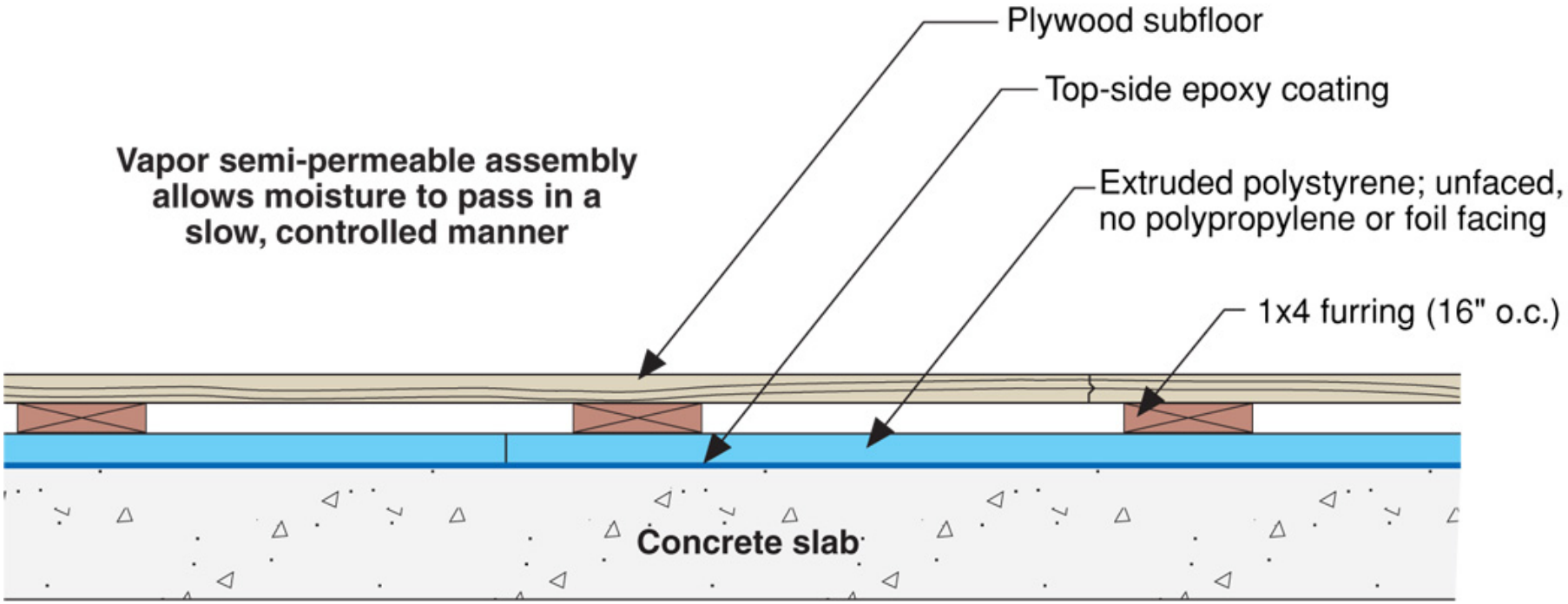

GRACE
Ice & Water Shield

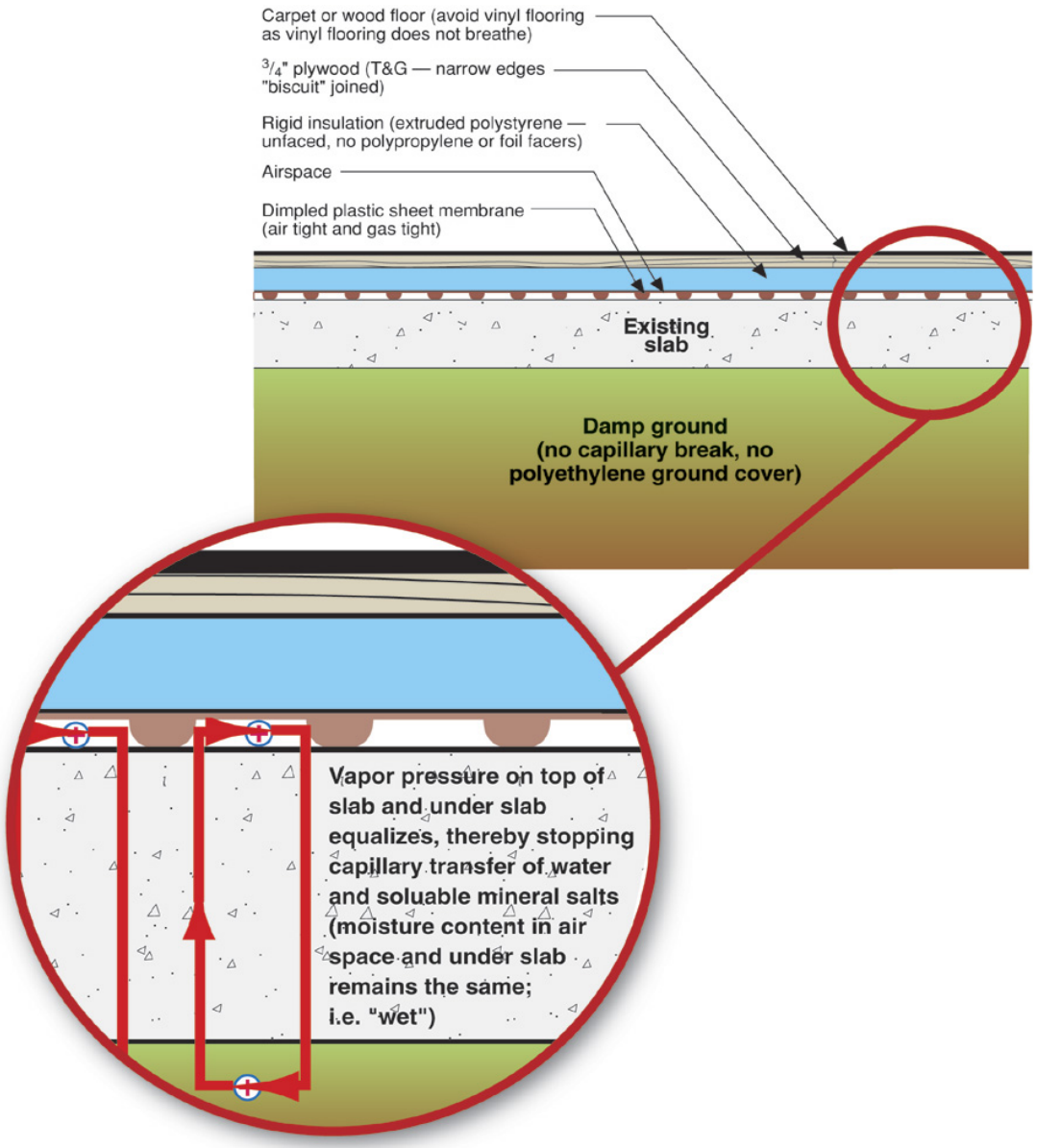

3” spray polyurethane foam
(2 lb/ft3 density)
1 1/2” metal stud wall
Gypsum board thermal barrier
3/4” drainage mat (filter fabric side facing up)
2” extruded polystyrene (XPS)
New concrete slab
Existing slab



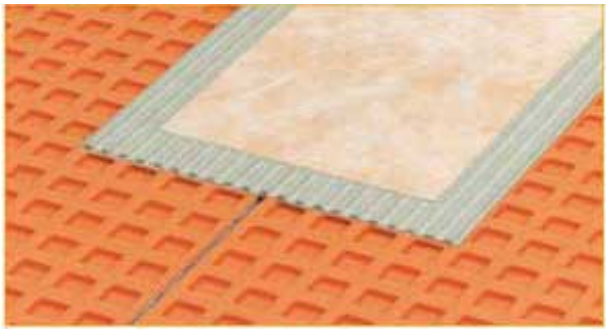

On Demand


Styrofoam
Styrofoam
Styrofoam
Styrofoam


Plywood subfloor
Top-side epoxy coating
Vapor semi-permeable assembly allows moisture to pass in a slow, controlled manner
Extruded polystyrene; unfaced, no polypropylene or foil facing
1x4 furring (16" o.c.)
Concrete slab


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 — unfaced, no polypropylene or foil facers)
Airspace
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 soluable mineral salts (moisture content in air space and under slab remains the same; i.e. "wet")


DELTA-FL

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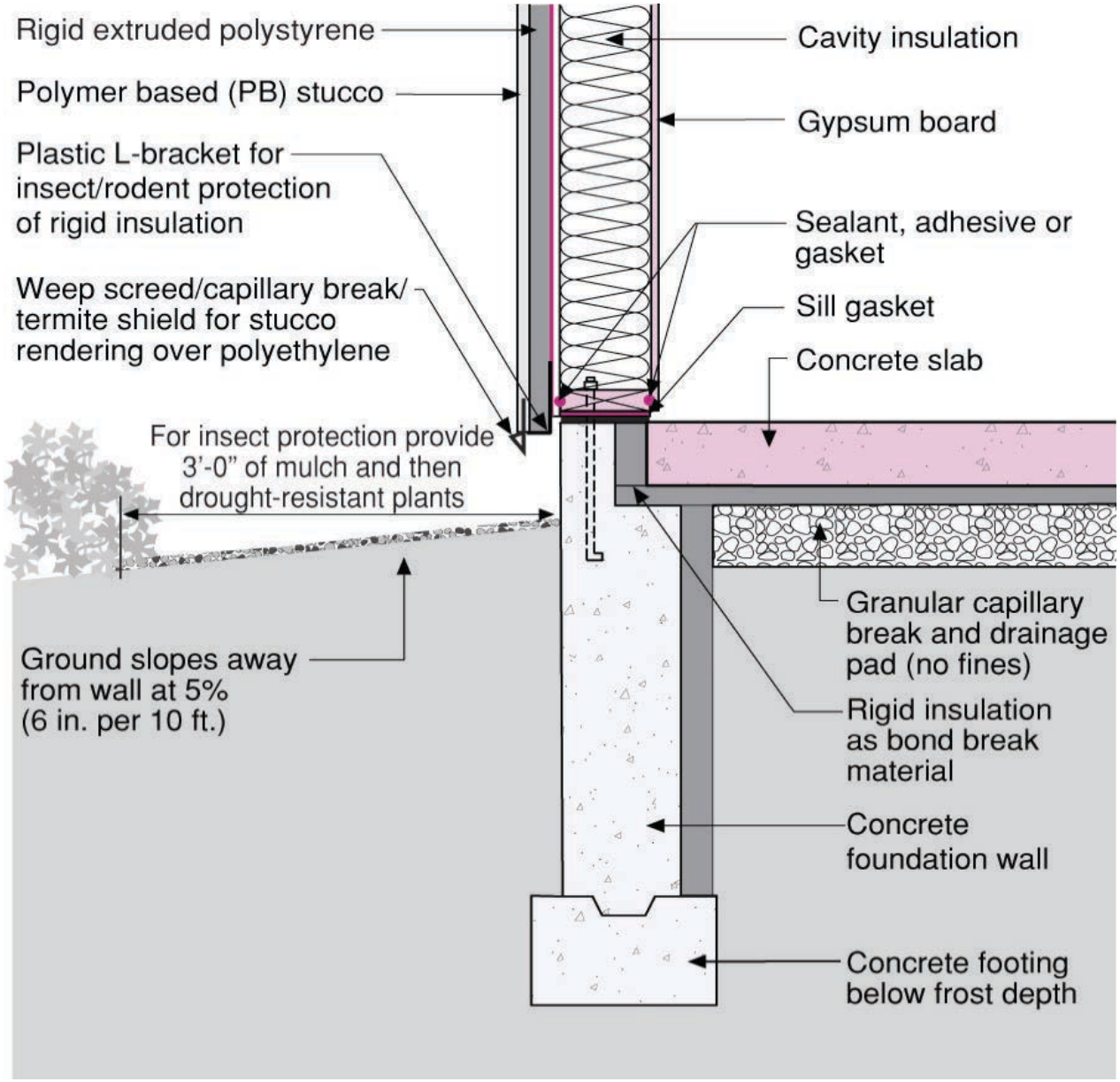
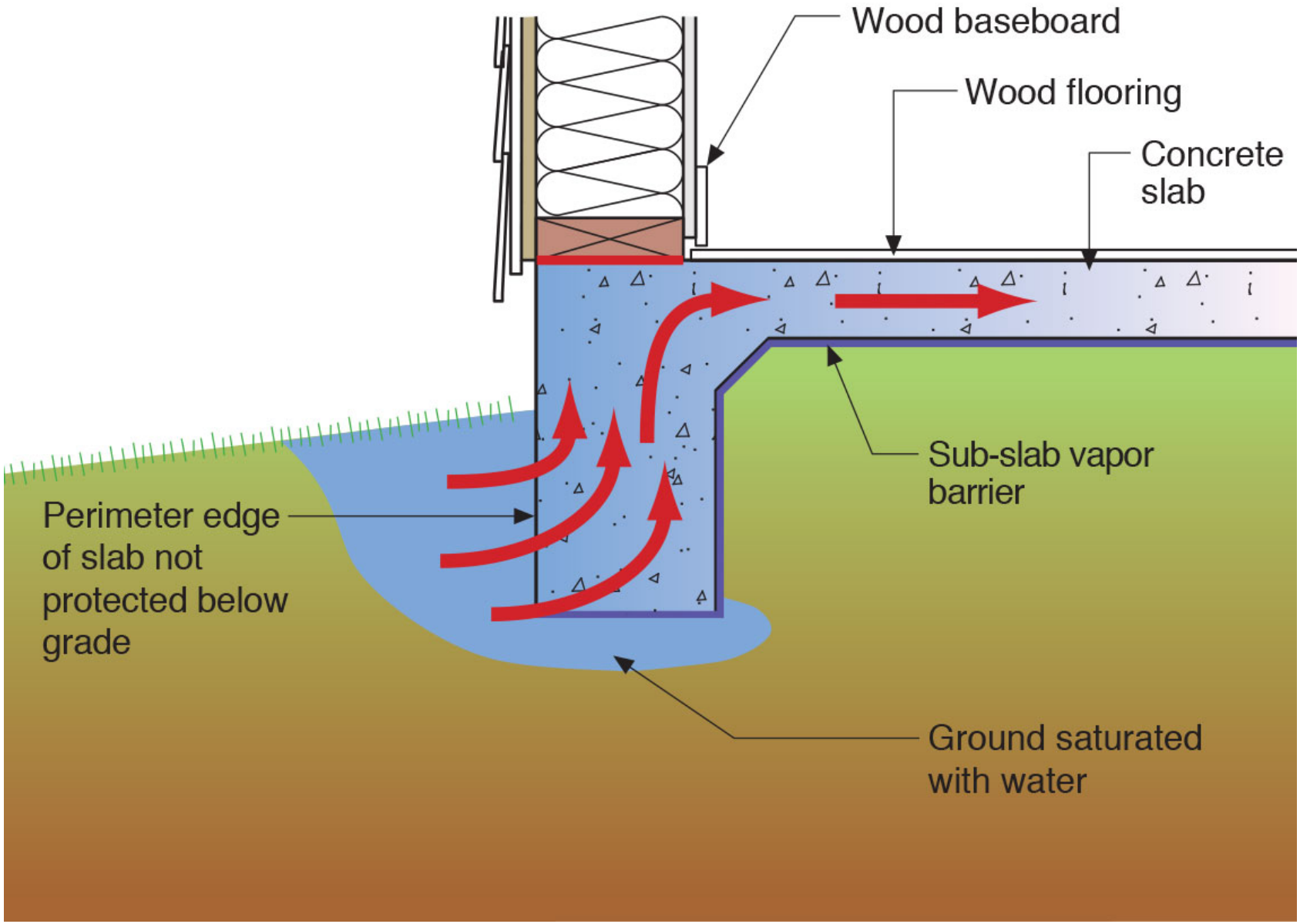
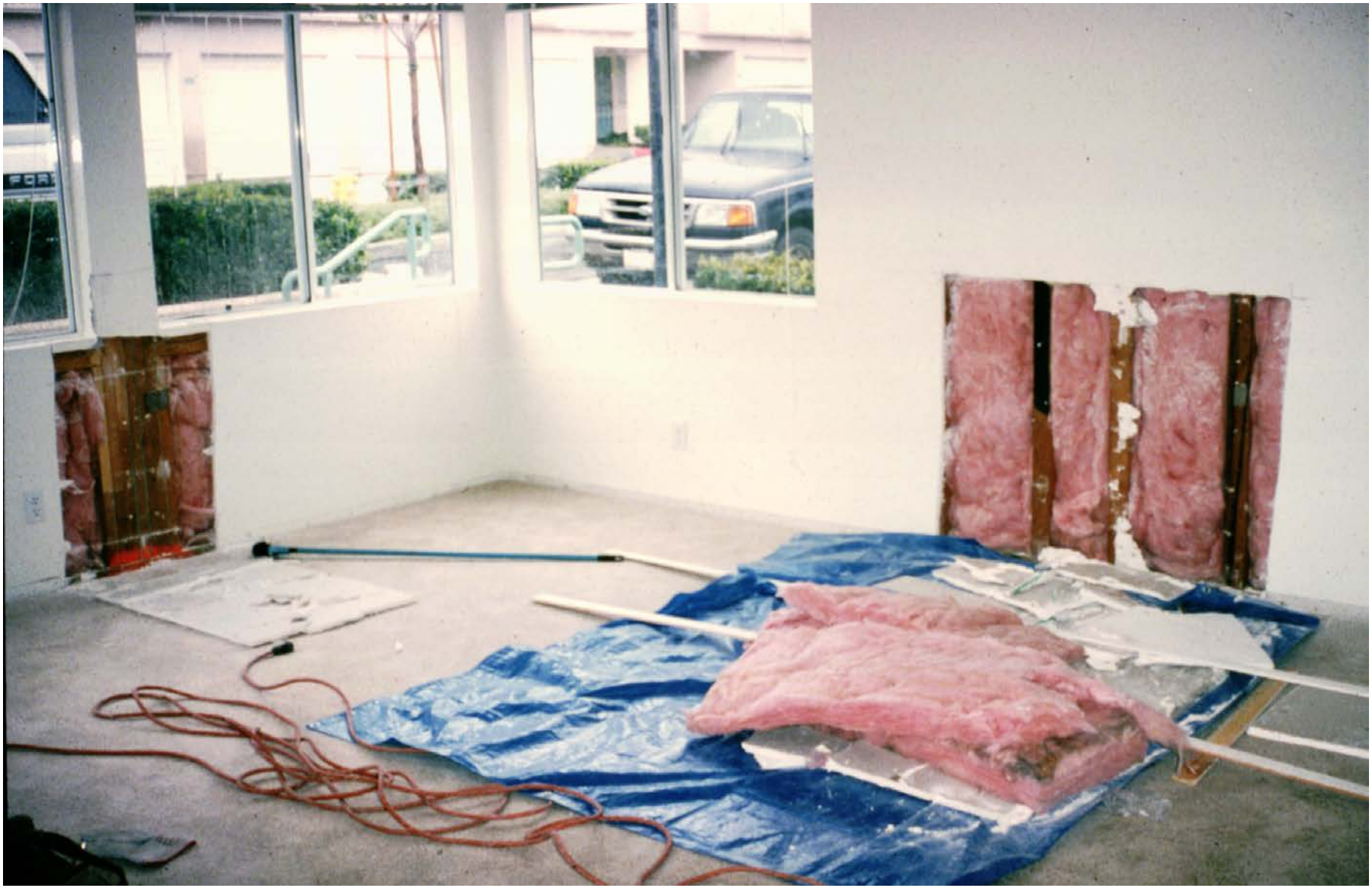
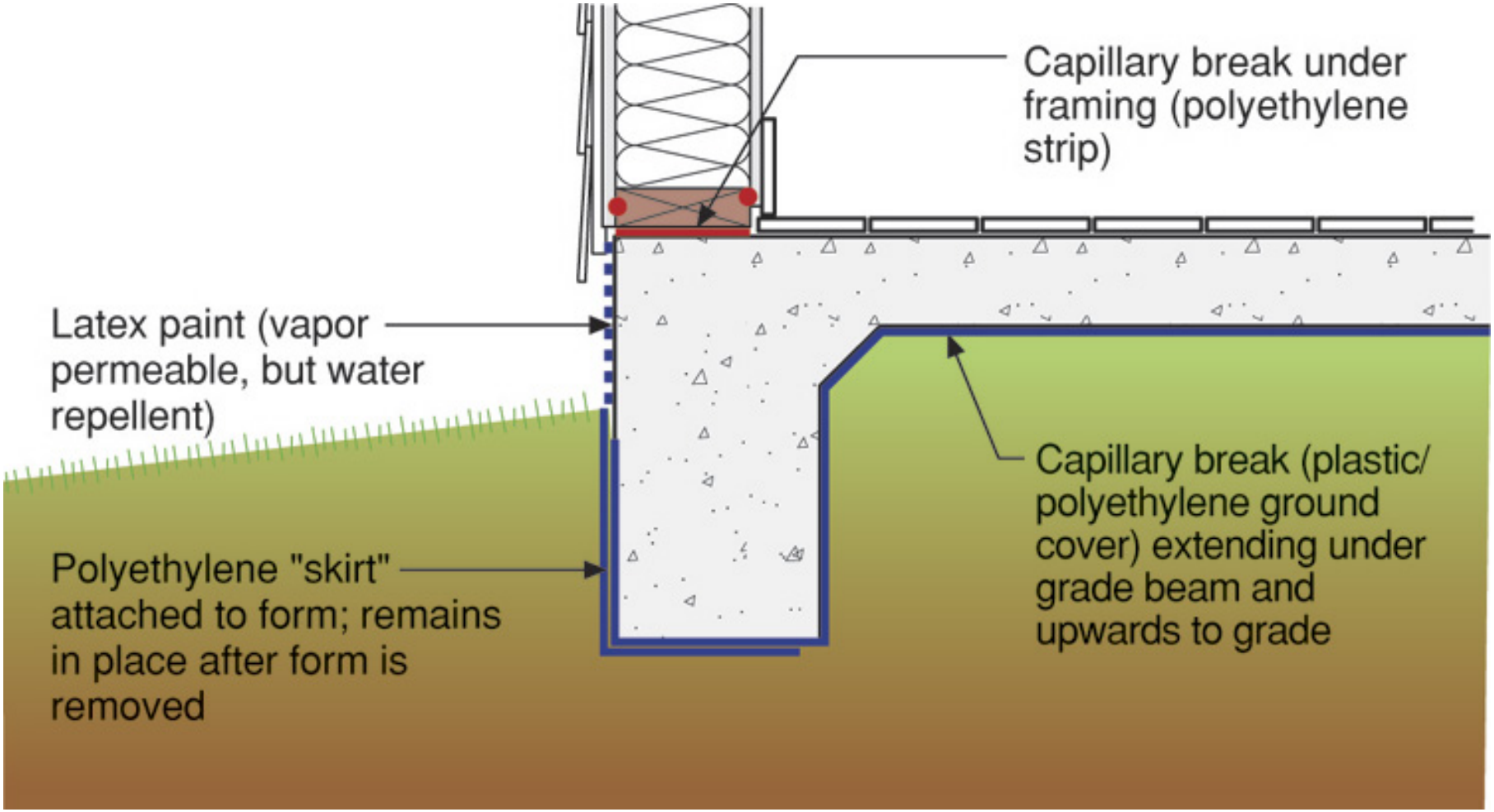

Rigid extruded polystyrene
Polymer based (PB) stucco
Plastic L-bracket for insect/rodent protection of rigid insulation
Weep screed/capillary break/ termite shield for stucco rendering over polyethylene
For insect protection provide 3'-0" of mulch and then drought-resistant plants
Ground slopes away from wall at 5% (6 in. per 10 ft.)
Cavity insulation
Gypsum board
Sealant, adhesive or gasket
Sill gasket
Concrete slab
Granular capillary break and drainage pad (no fines)
Rigid insulation as bond break material
Concrete foundation wall
Concrete footing below frost depth

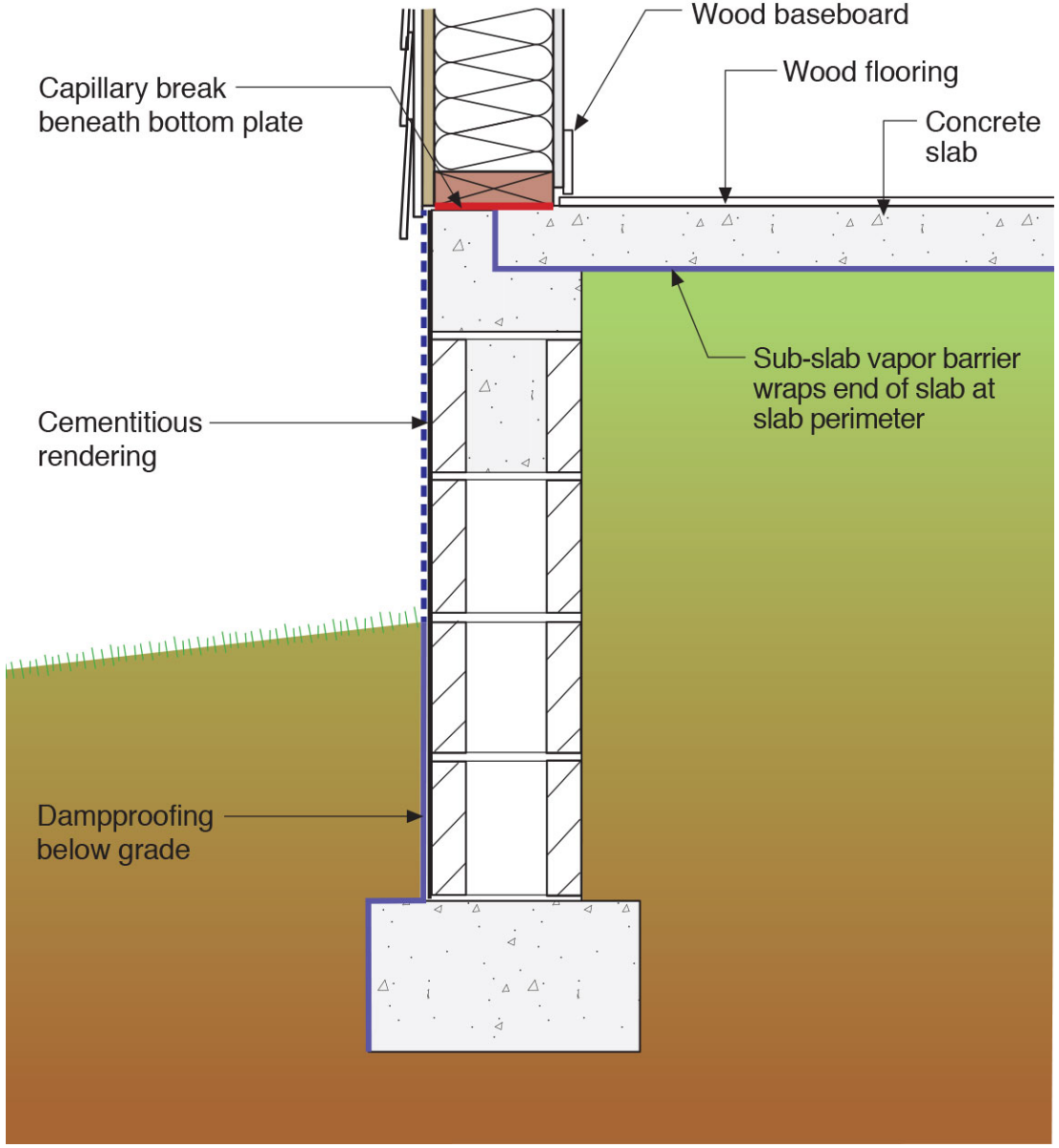

Wood baseboard
Wood flooring
Concrete slab
Sub-slab vapor barrier
Perimeter edge of slab not protected below grade
Ground saturated with water

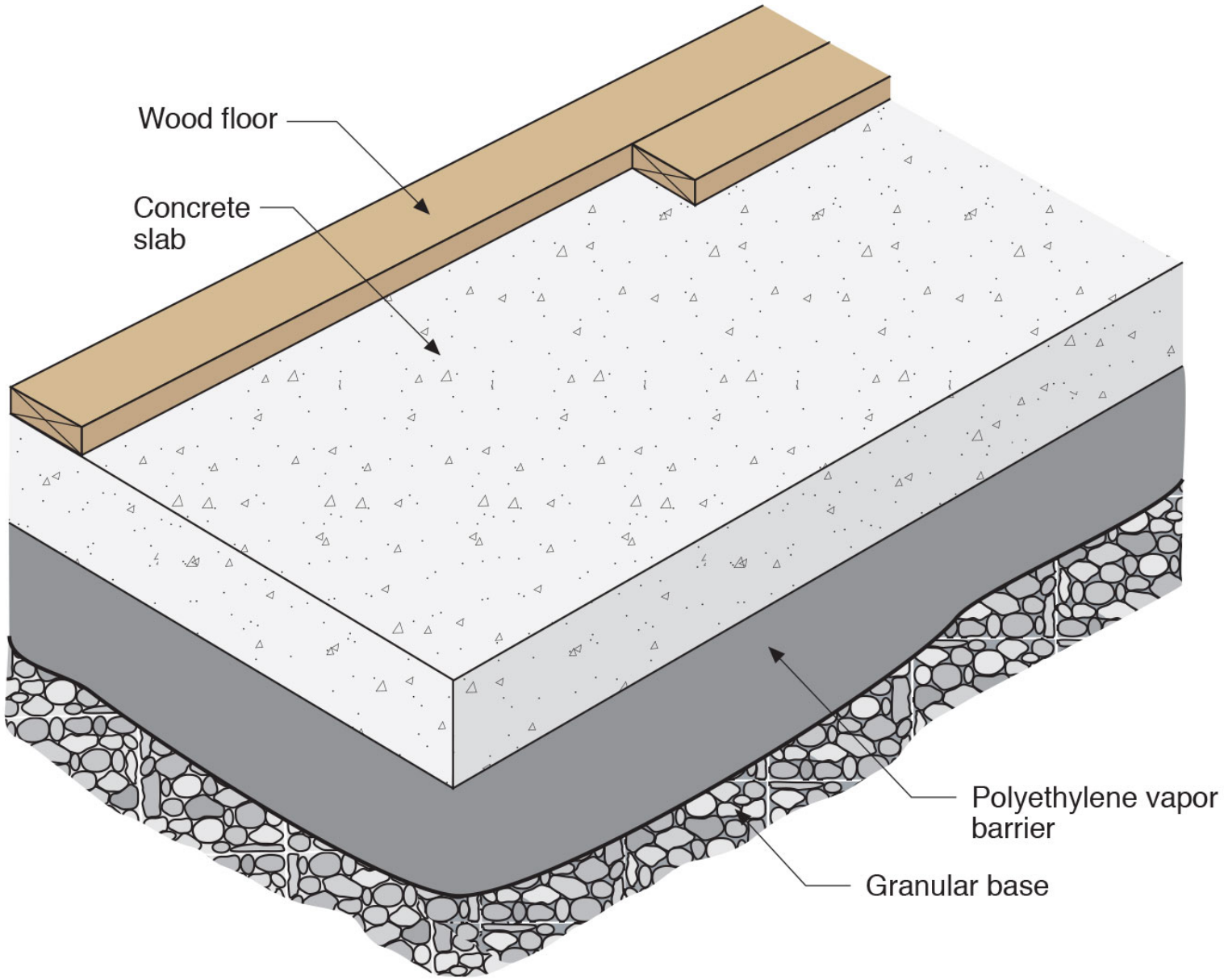

25
U-HAU

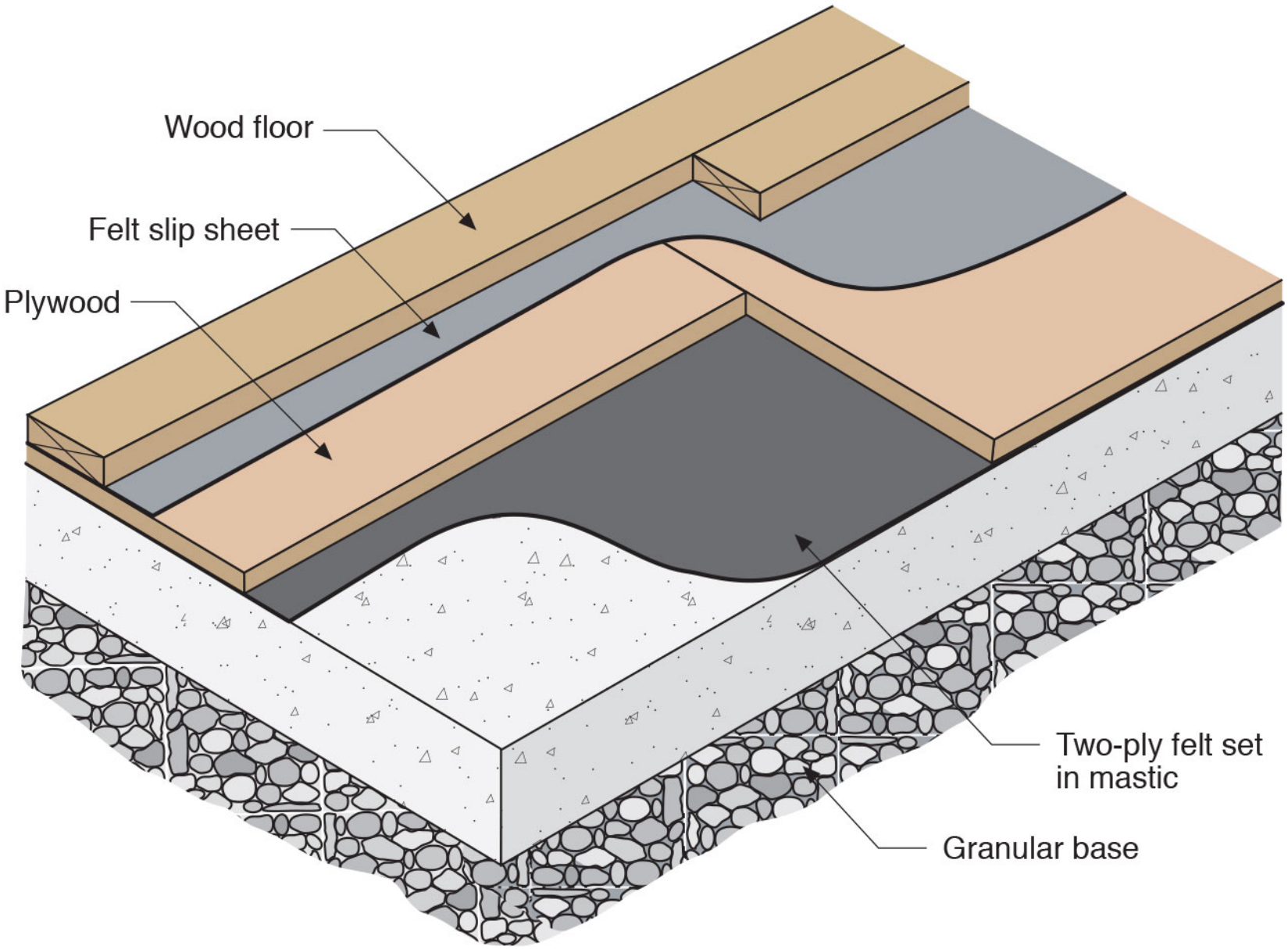

FORD

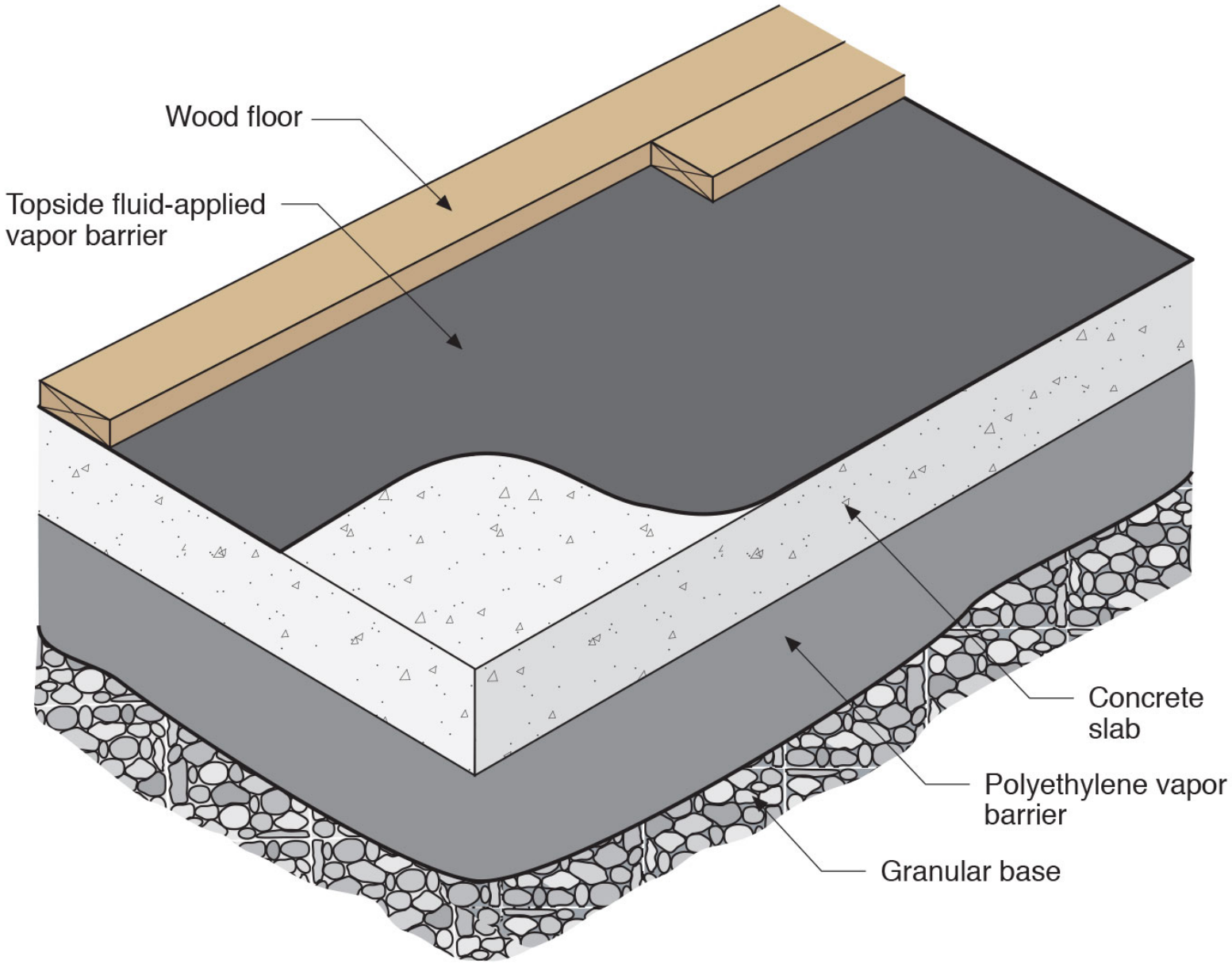



Capillary break under framing (polyethylene strip)
Latex paint (vapor permeable, but water repellent)
Polyethylene "skirt" attached to form; remains in place after form is removed
Capillary break (plastic/ polyethylene ground cover) extending under grade beam and upwards to grade

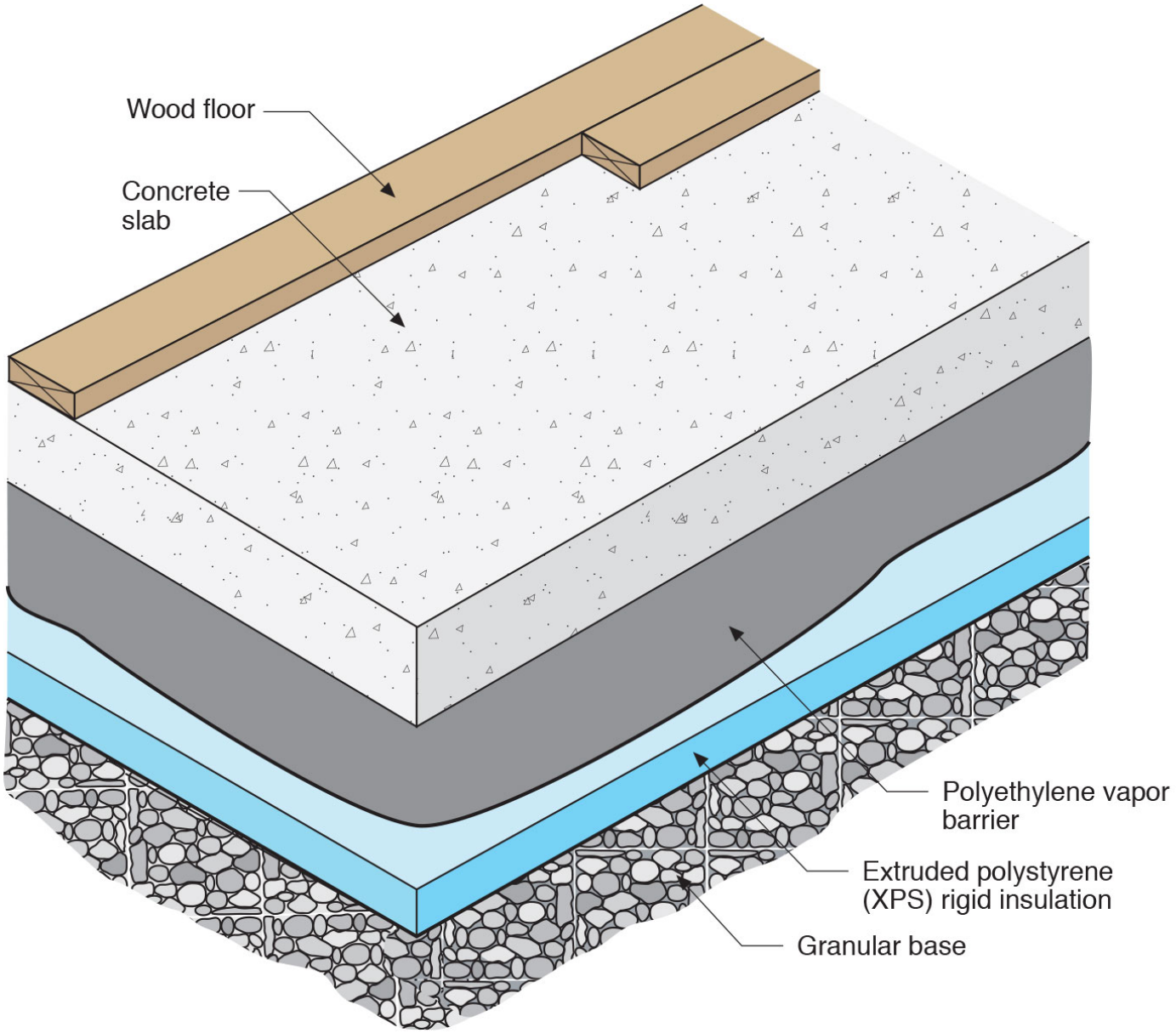

Wood baseboard
Wood flooring
Concrete slab
Capillary break beneath bottom plate
Sub-slab vapor barrier wraps end of slab at slab perimeter
Cementitious rendering
Dampproofing below grade

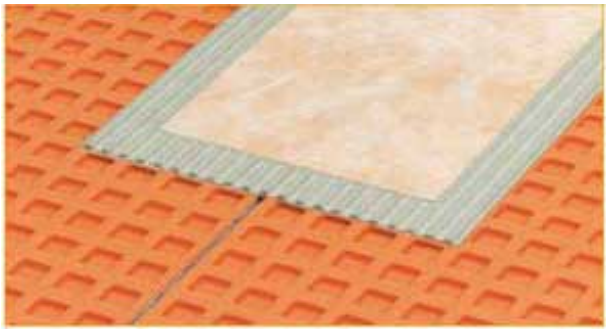

Wood floor
Concrete slab
Polyethylene vapor barrier
Granular base


Wood floor
Felt slip sheet
Plywood
Two-ply felt set
in mastic
Granular base

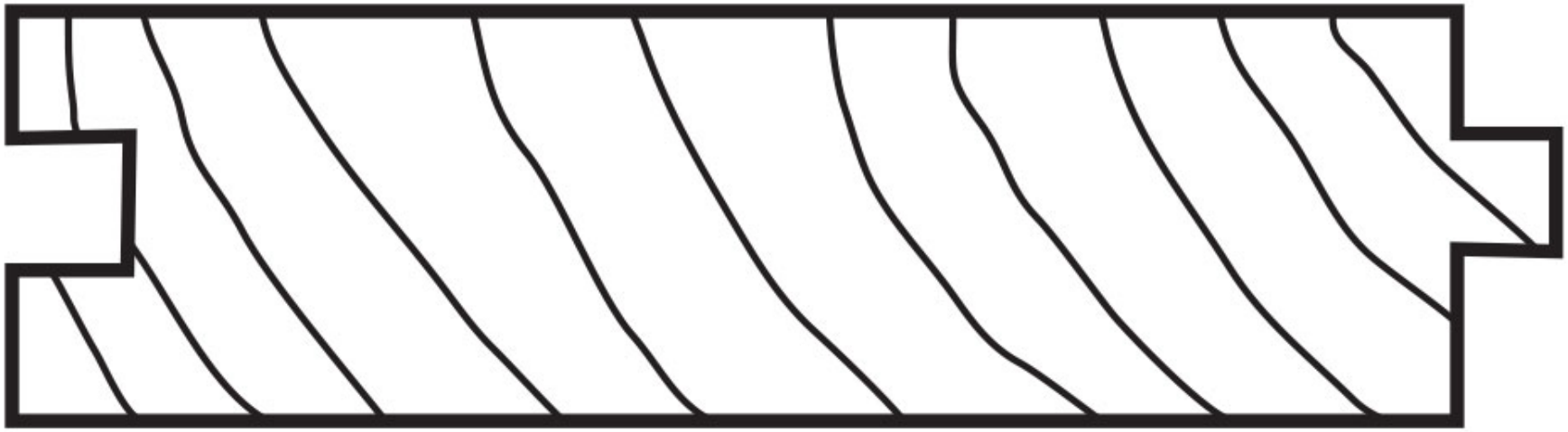

Wood floor
Topside fluid-applied vapor barrier
Concrete slab
Polyethylene vapor barrier
Granular base


COLA


Wood floor
Concrete slab
Polyethylene vapor barrier
Extruded polystyrene (XPS) rigid insulation
Granular base

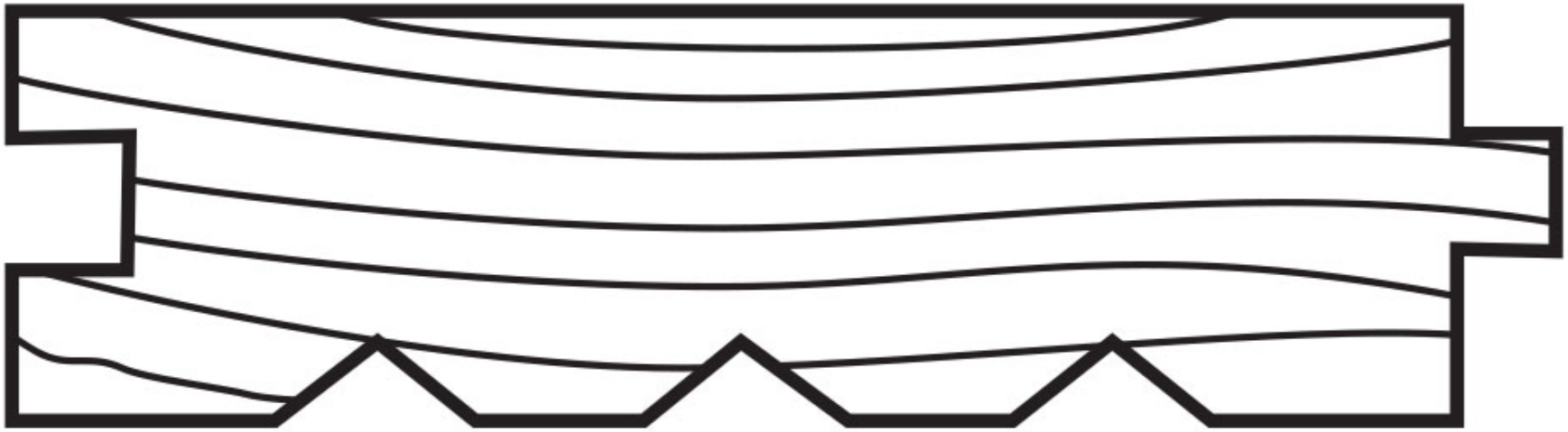



SHEETR
All Purpose
Joint Compound

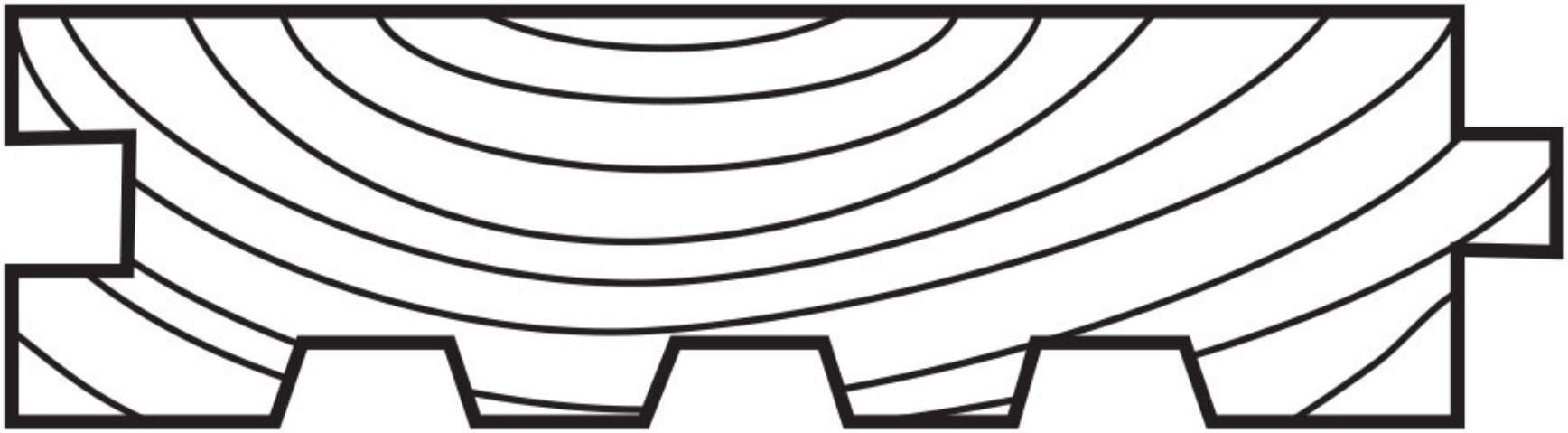


Plain

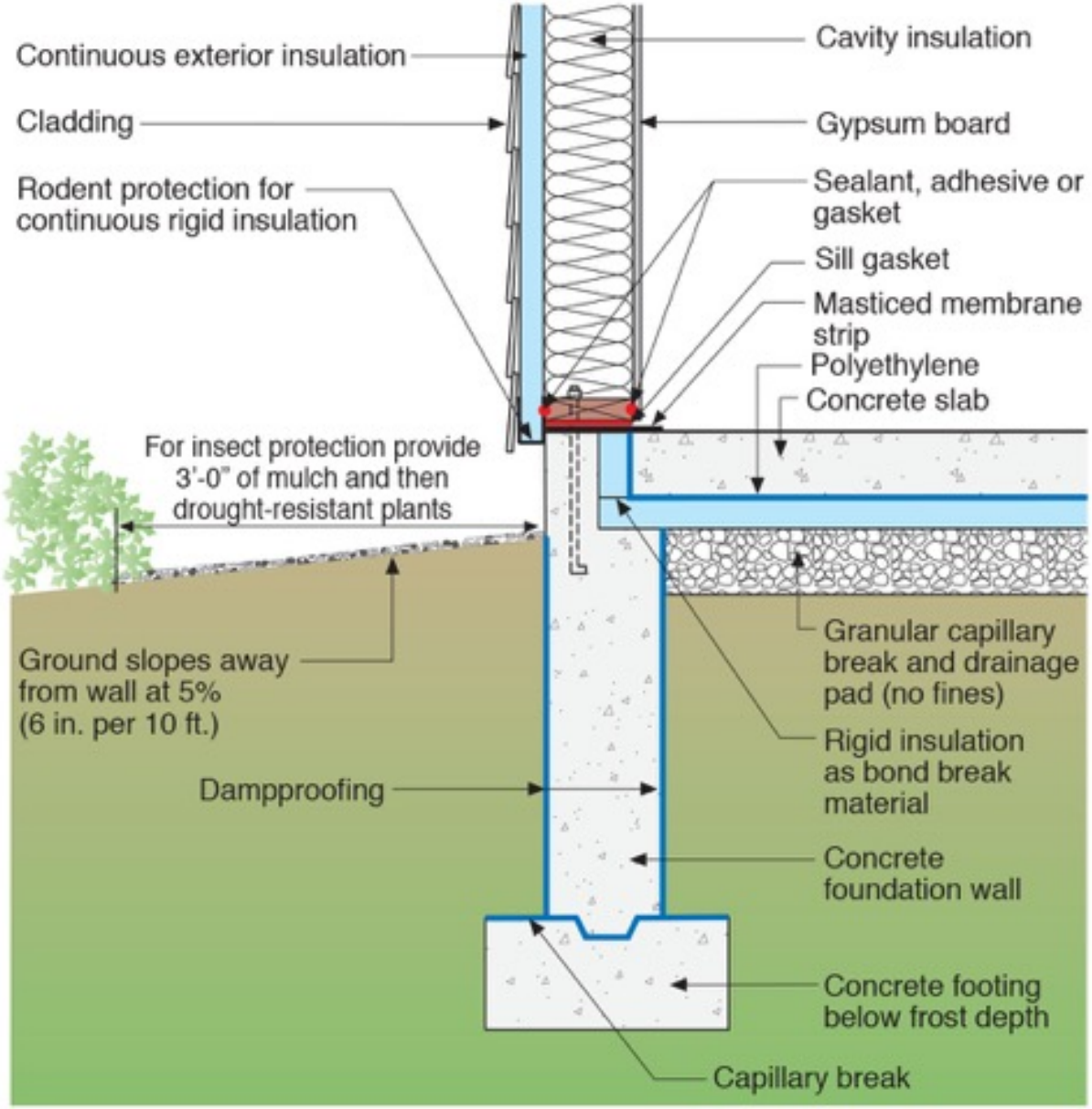
Hollow Back

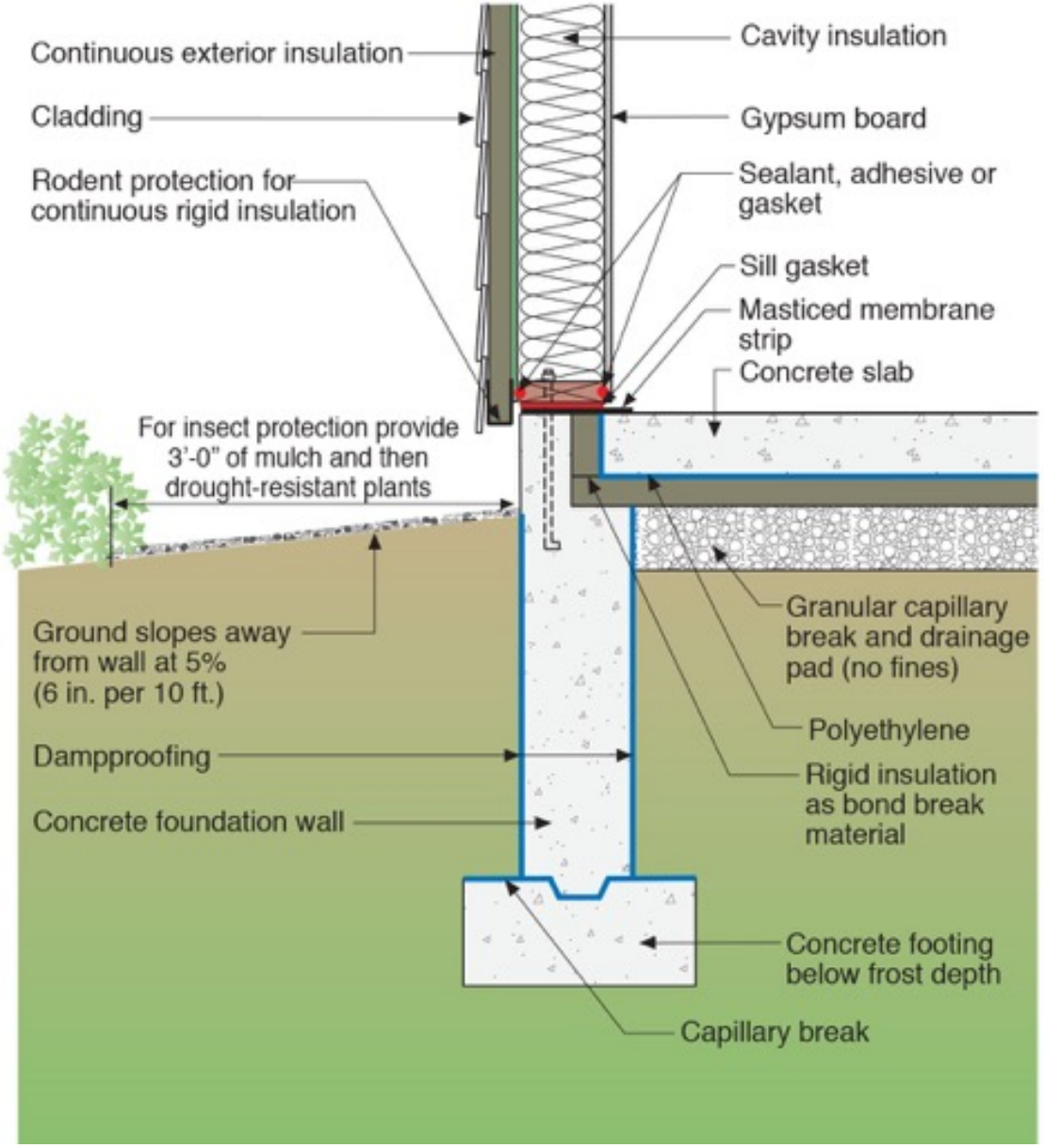


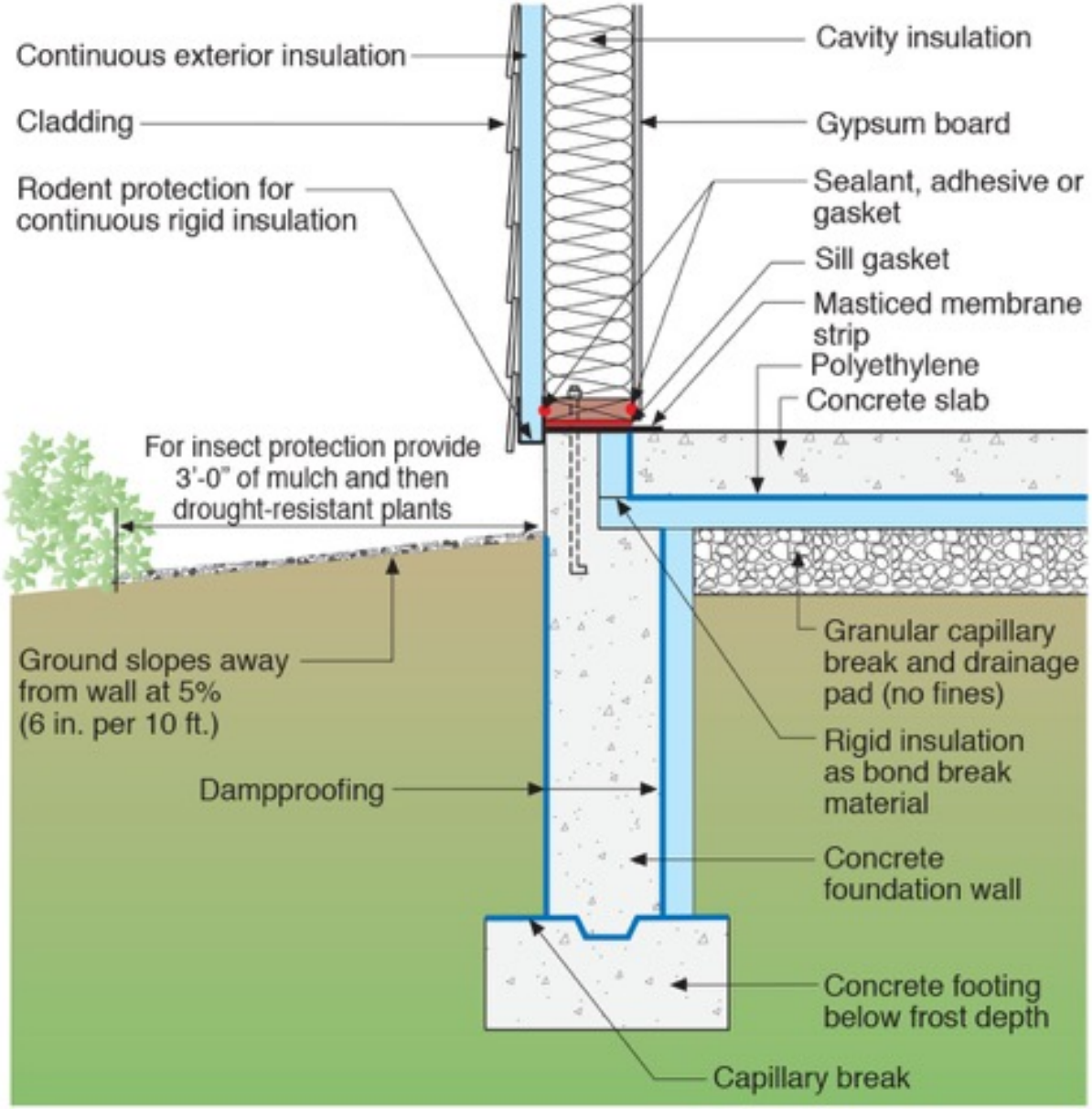
Scratch Back

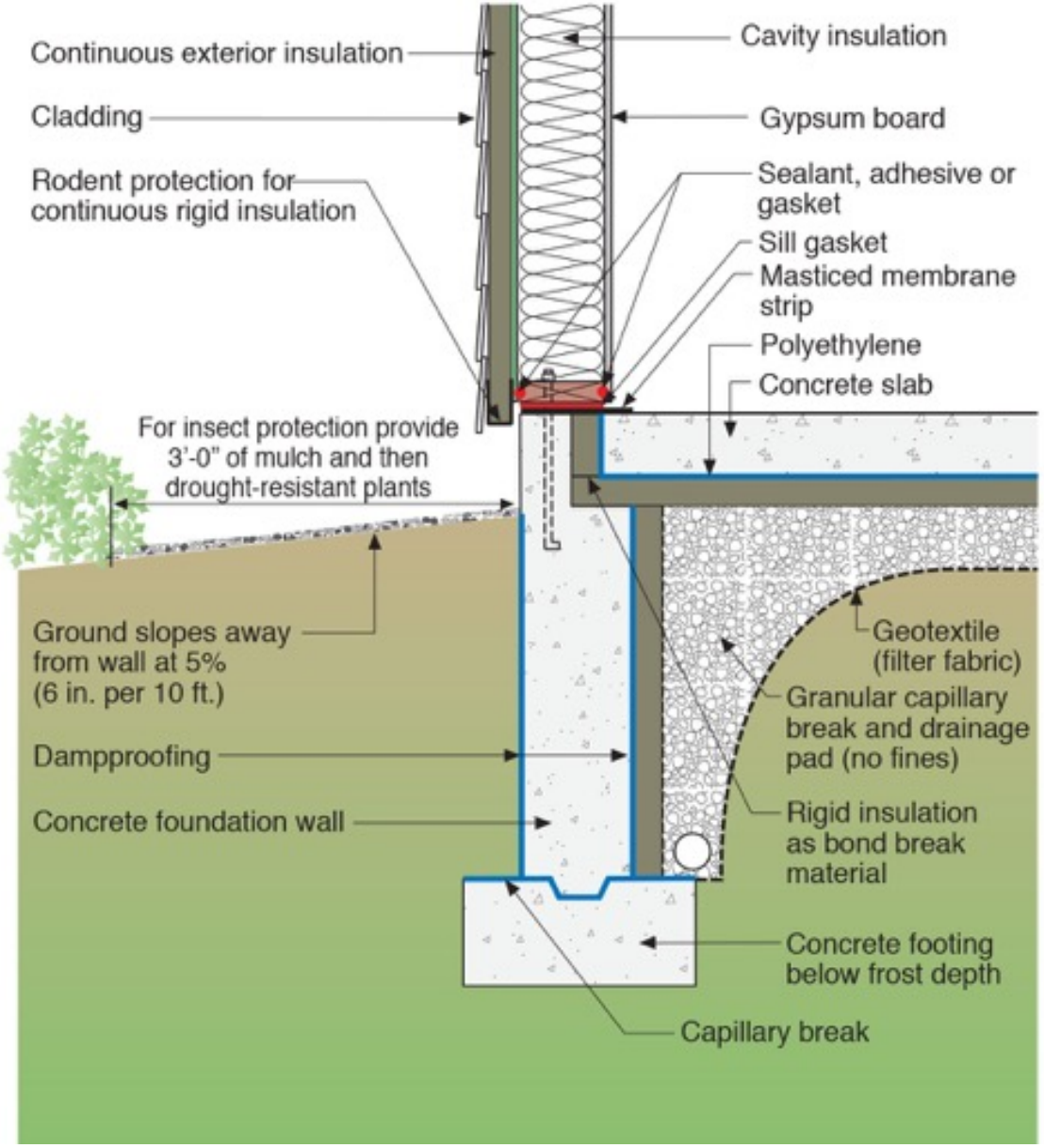


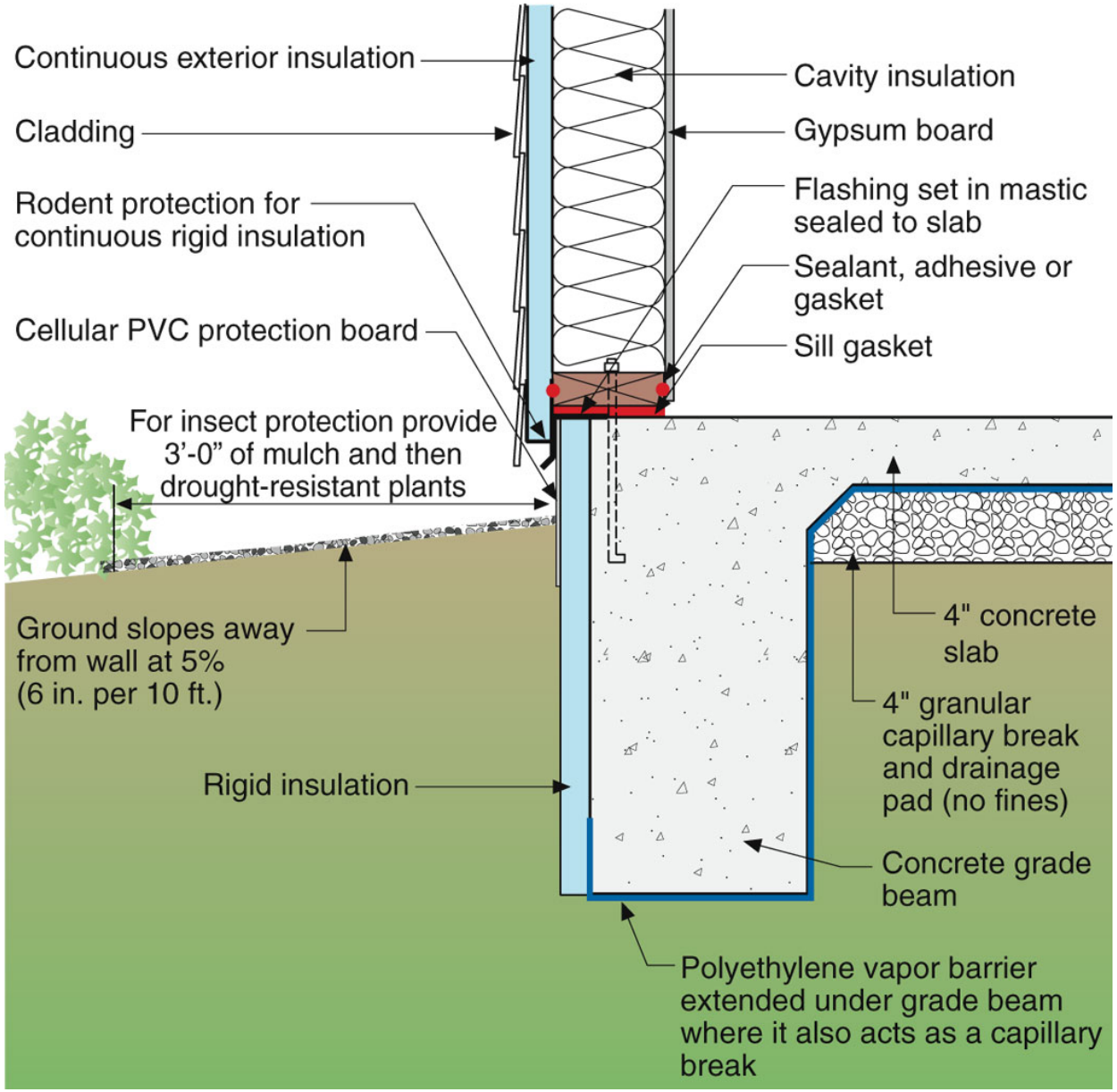
Hollow or Scratch Back

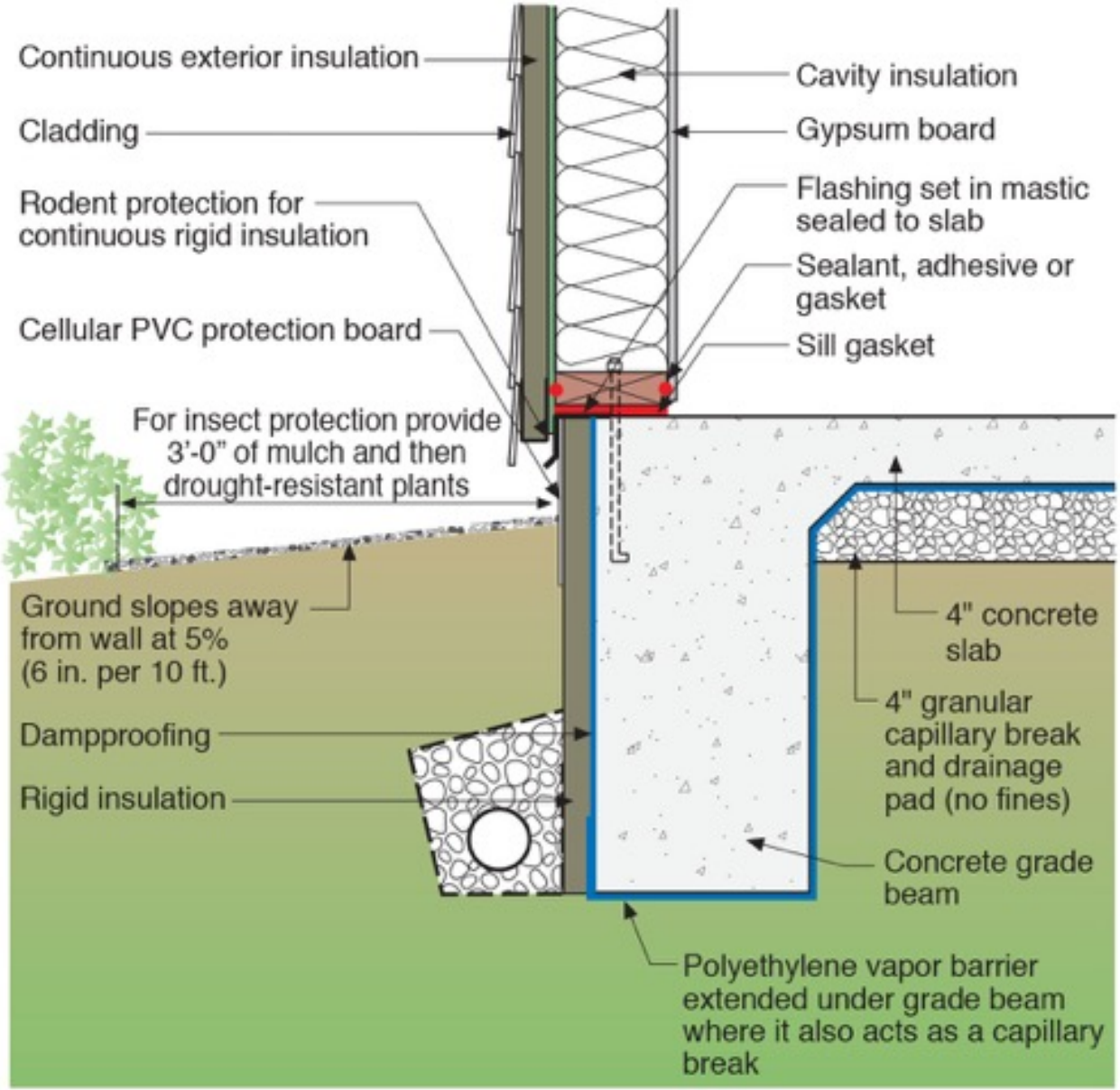

Continuous exterior insulation
Cladding
Rodent protection for continuous rigid insulation
Cavity insulation
Gypsum board
Sealant, adhesive or gasket
Sill gasket
Masticed membrane strip
Polyethylene
Concrete slab
For insect protection provide 3'-0" of mulch and then drought-resistant plants
Ground slopes away from wall at 5% (6 in. per 10 ft.)
Dampproofing
Granular capillary break and drainage pad (no fines)
Rigid insulation as bond break material
Concrete foundation wall
Concrete footing below frost depth
Capillary break

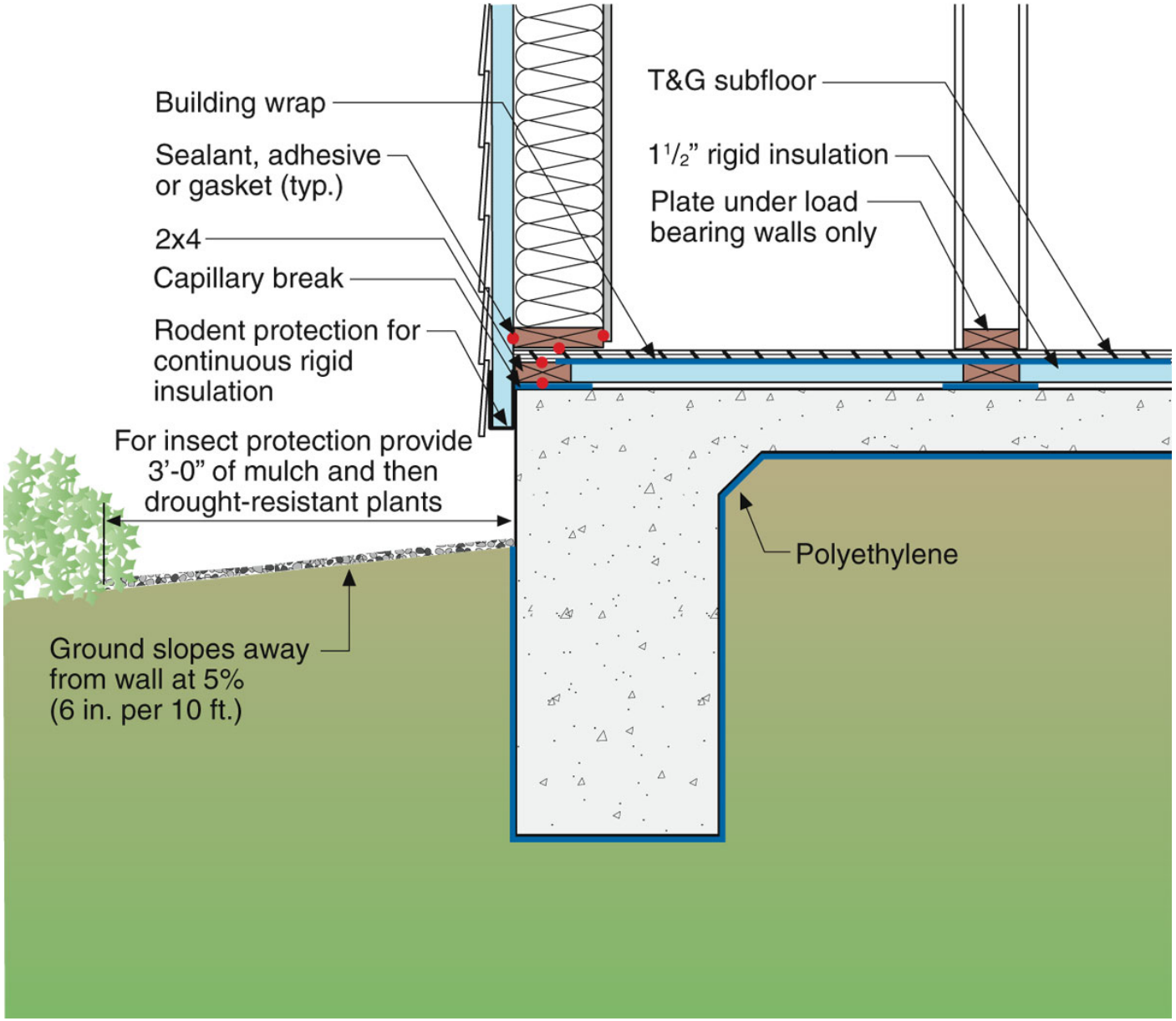

Continuous exterior insulation
Cladding
Rodent protection for continuous rigid insulation
Cavity insulation
Gypsum board
Sealant, adhesive or gasket
Sill gasket
Masticed membrane strip
Concrete slab
For insect protection provide 3'-0" of mulch and then drought-resistant plants
Ground slopes away from wall at 5% (6 in. per 10 ft.)
Dampproofing
Concrete foundation wall
Granular capillary break and drainage pad (no fines)
Polyethylene
Rigid insulation as bond break material
Concrete footing below frost depth
Capillary break

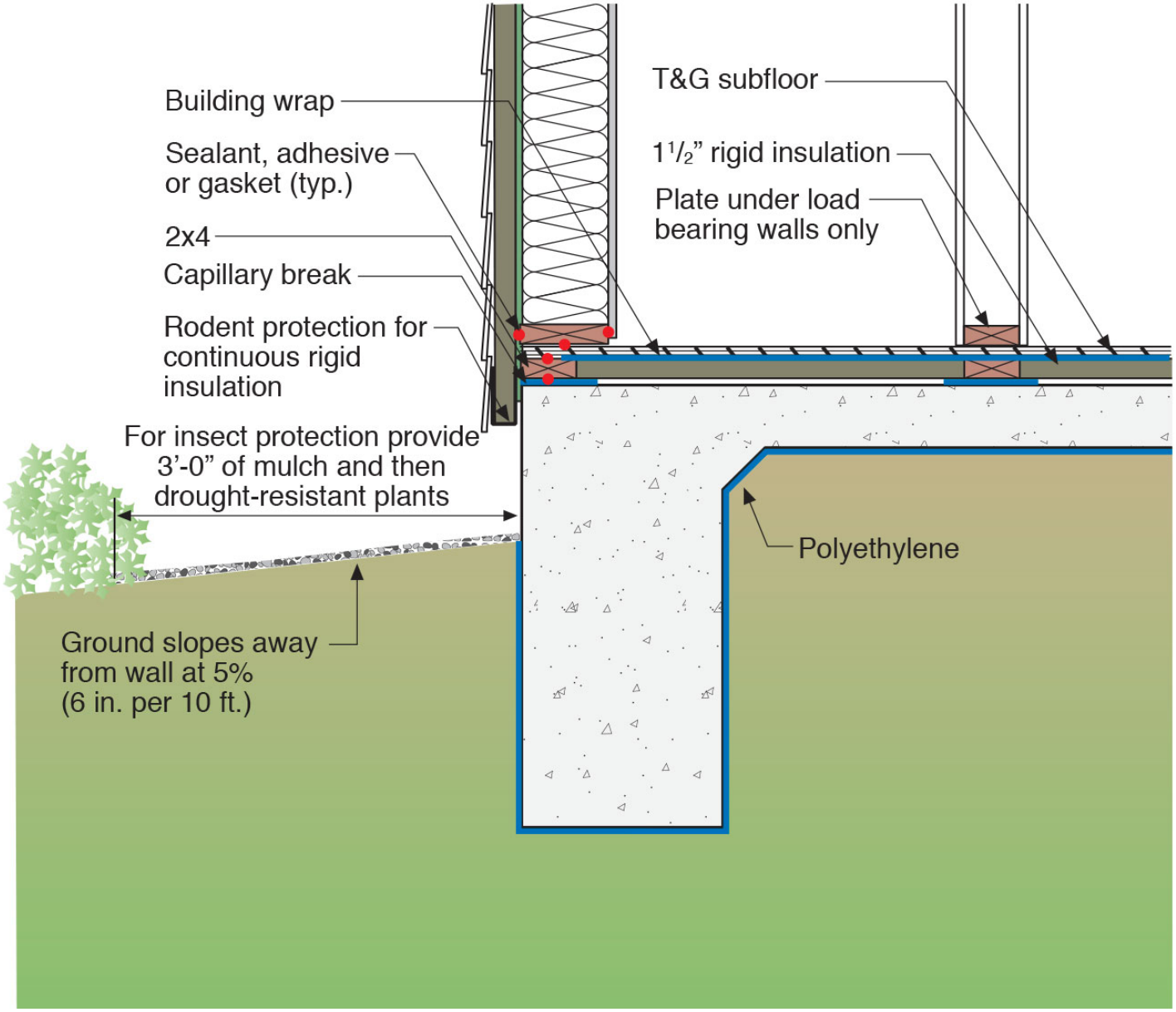

Continuous exterior insulation
Cladding
Rodent protection for continuous rigid insulation
Cavity insulation
Gypsum board
Sealant, adhesive or gasket
Sill gasket
Masticed membrane strip
Polyethylene
Concrete slab
For insect protection provide 3'-0" of mulch and then drought-resistant plants
Ground slopes away from wall at 5% (6 in. per 10 ft.)
Dampproofing
Granular capillary break and drainage pad (no fines)
Rigid insulation as bond break material
Concrete foundation wall
Concrete footing below frost depth
Capillary break

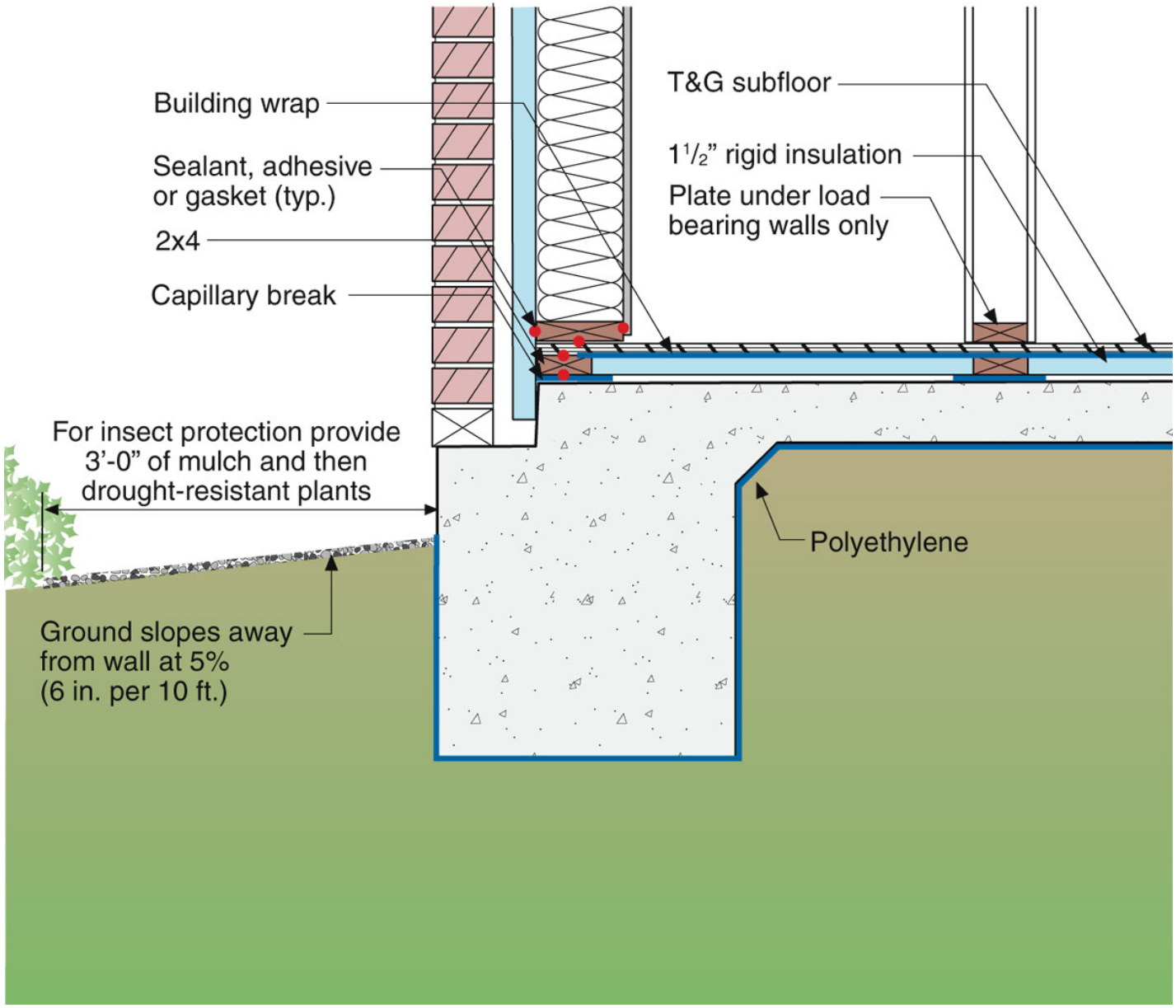

Continuous exterior insulation
Cladding
Rodent protection for continuous rigid insulation
Cavity insulation
Gypsum board
Sealant, adhesive or gasket
Sill gasket
Masticed membrane strip
Polyethylene
Concrete slab
For insect protection provide 3'-0" of mulch and then drought-resistant plants
Ground slopes away from wall at 5% (6 in. per 10 ft.)
Dampproofing
Concrete foundation wall
Geotextile (filter fabric)
Granular capillary break and drainage pad (no fines)
Rigid insulation as bond break material
Concrete footing below frost depth
Capillary break

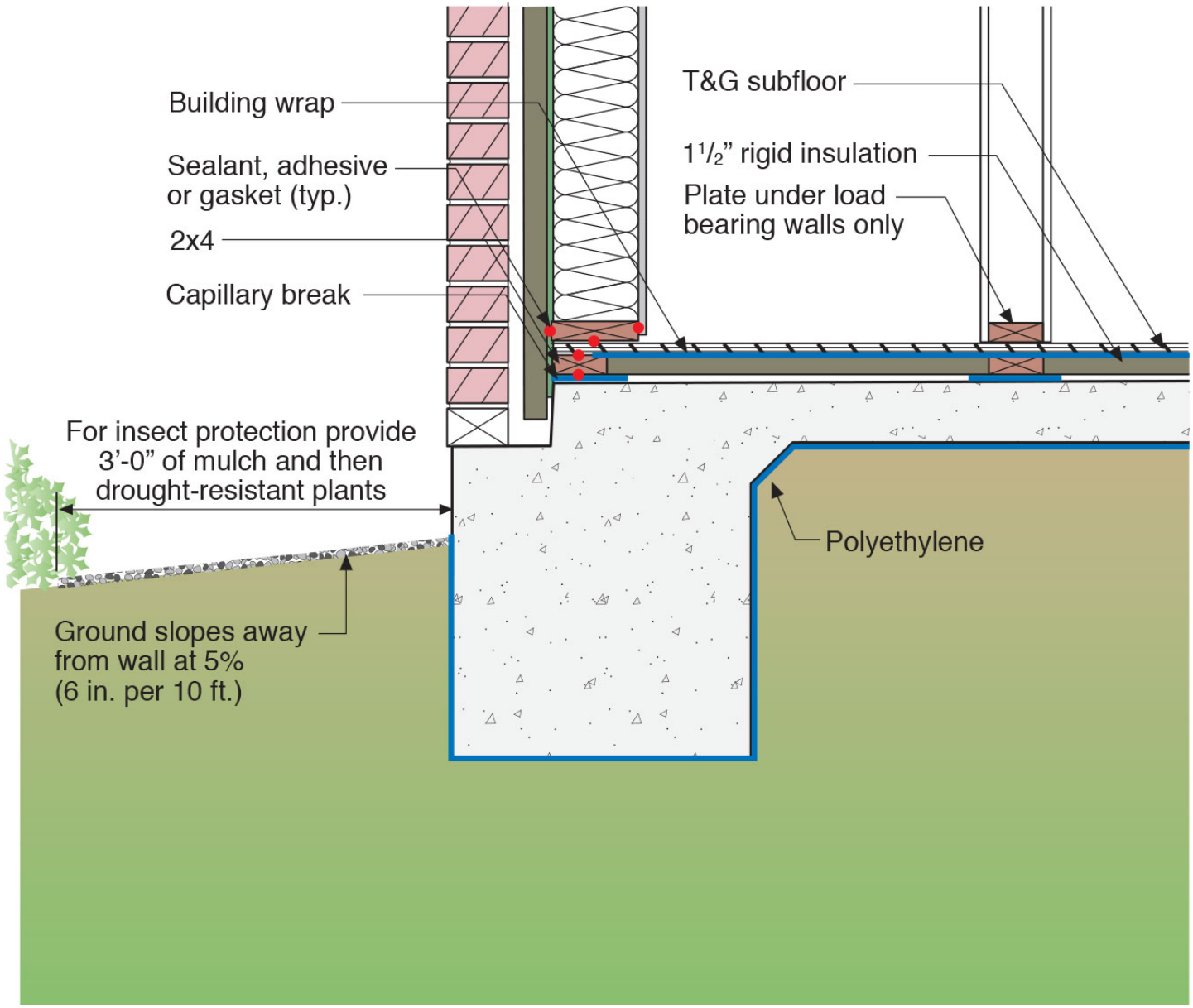

Continuous exterior insulation
Cladding
Rodent protection for continuous rigid insulation
Cellular PVC protection board
For insect protection provide 3'-0" of mulch and then drought-resistant plants
Ground slopes away from wall at 5% (6 in. per 10 ft.)
Rigid insulation
Cavity insulation
Gypsum board
Flashing set in mastic sealed to slab
Sealant, adhesive or gasket
Sill gasket
4" concrete slab
4" granular capillary break and drainage pad (no fines)
Concrete grade beam
Polyethylene vapor barrier extended under grade beam where it also acts as a capillary break

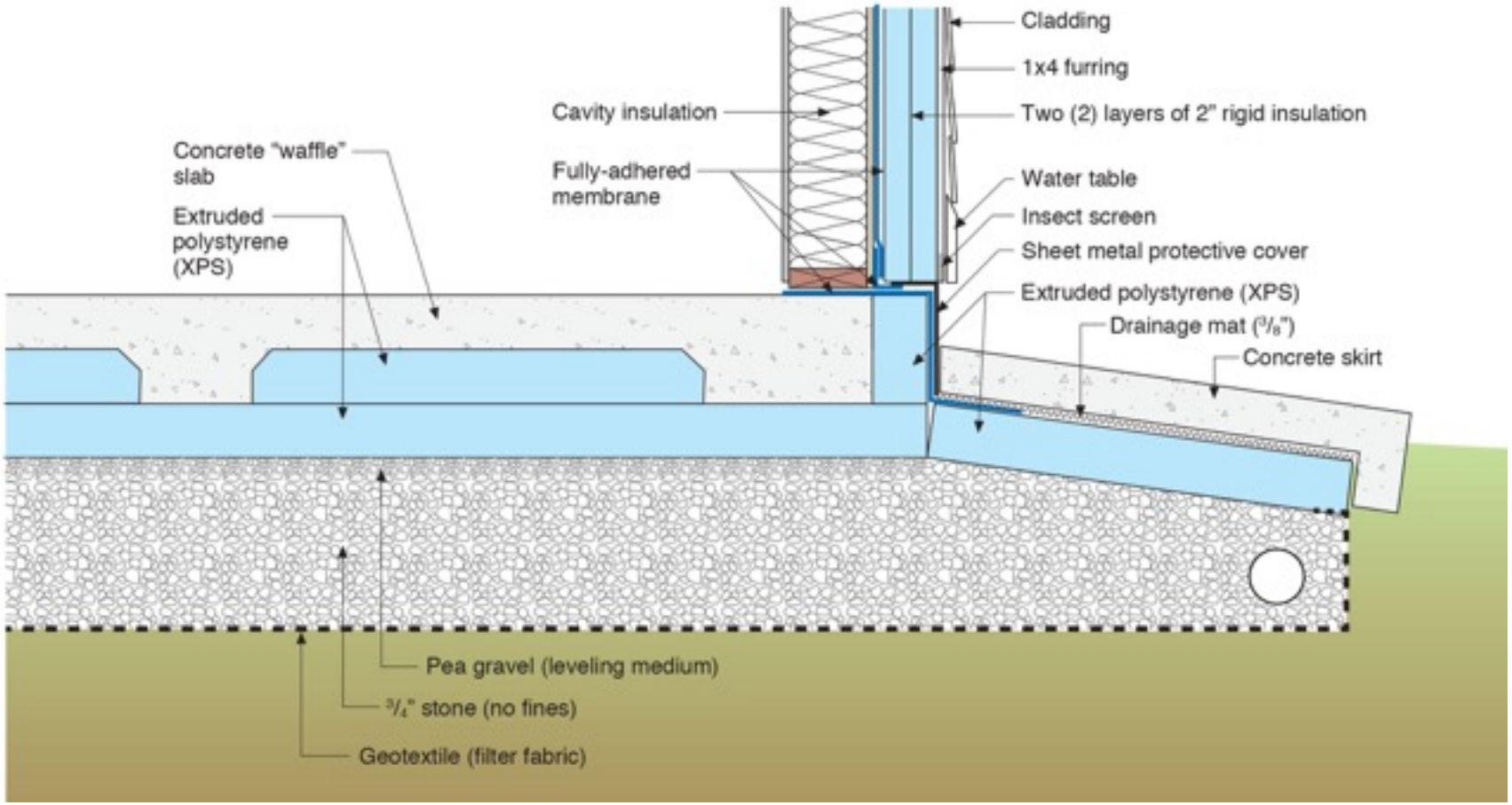

Continuous exterior insulation
Cladding
Rodent protection for continuous rigid insulation
Cellular PVC protection board
For insect protection provide 3'-0" of mulch and then drought-resistant plants
Ground slopes away from wall at 5% (6 in. per 10 ft.)
Dampproofing
Rigid insulation
Cavity insulation
Gypsum board
Flashing set in mastic sealed to slab
Sealant, adhesive or gasket
Sill gasket
4" concrete slab
4" granular capillary break and drainage pad (no fines)
Concrete grade beam
Polyethylene vapor barrier extended under grade beam where it also acts as a capillary break

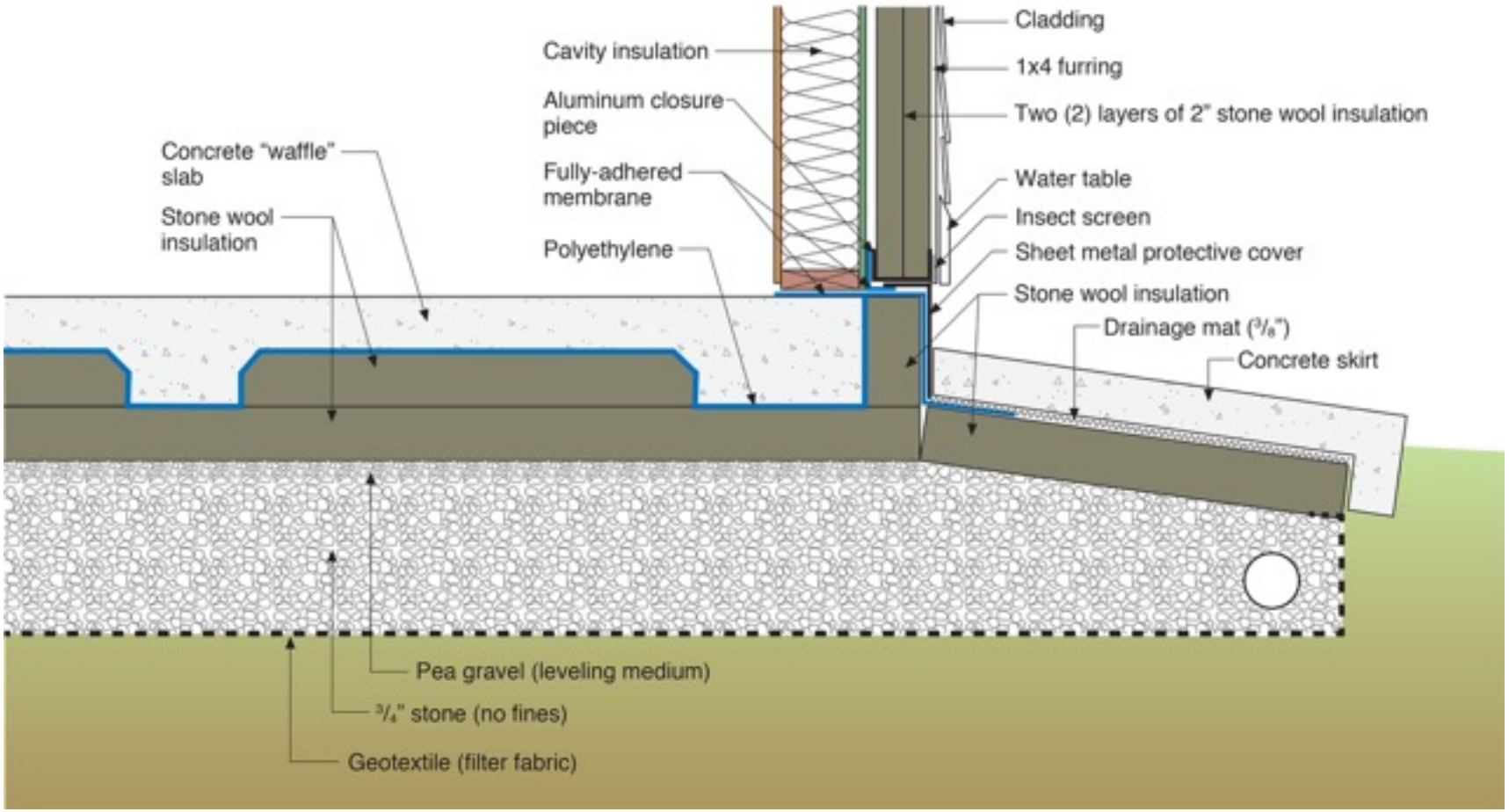

Building wrap
Sealant, adhesive or gasket (typ.)
2x4
Capillary break
Rodent protection for continuous rigid insulation
For insect protection provide 3'-0" of mulch and then drought-resistant plants
Ground slopes away from wall at 5% (6 in. per 10 ft.)
T&G subfloor
1½" rigid insulation
Plate under load bearing walls only
Polyethylene


Building wrap
Sealant, adhesive or gasket (typ.)
2x4
Capillary break
Rodent protection for continuous rigid insulation
For insect protection provide 3'-0" of mulch and then drought-resistant plants
Ground slopes away from wall at 5% (6 in. per 10 ft.)
T&G subfloor
1½" rigid insulation
Plate under load bearing walls only
Polyethylene


Building wrap
Sealant, adhesive or gasket (typ.)
2x4
Capillary break
T&G subfloor
1½" rigid insulation
Plate under load bearing walls only
For insect protection provide 3'-0" of mulch and then drought-resistant plants
Polyethylene
Ground slopes away from wall at 5% (6 in. per 10 ft.)


Building wrap
Sealant, adhesive or gasket (typ.)
2x4
Capillary break
T&G subfloor
1½" rigid insulation
Plate under load bearing walls only
For insect protection provide 3'-0" of mulch and then drought-resistant plants
Polyethylene
Ground slopes away from wall at 5% (6 in. per 10 ft.)


Cladding
1x4 furring
Two (2) layers of 2" rigid insulation
Cavity insulation
Fully-adhered membrane
Concrete "waffle" slab
Extruded polystyrene (XPS)
Water table
Insect screen
Sheet metal protective cover
Extruded polystyrene (XPS)
Drainage mat (3/8")
Concrete skirt
Pea gravel (leveling medium)
3/4" stone (no fines)
Geotextile (filter fabric)


Cladding
1x4 furring
Two (2) layers of 2" stone wool insulation
Water table
Insect screen
Sheet metal protective cover
Stone wool insulation
Drainage mat (3/8")
Concrete skirt
Cavity insulation
Aluminum closure piece
Fully-adhered membrane
Polyethylene
Concrete "waffle" slab
Stone wool insulation
Pea gravel (leveling medium)
3/4" stone (no fines)
Geotextile (filter fabric)


ROXUL
ROXUL
ROXUL

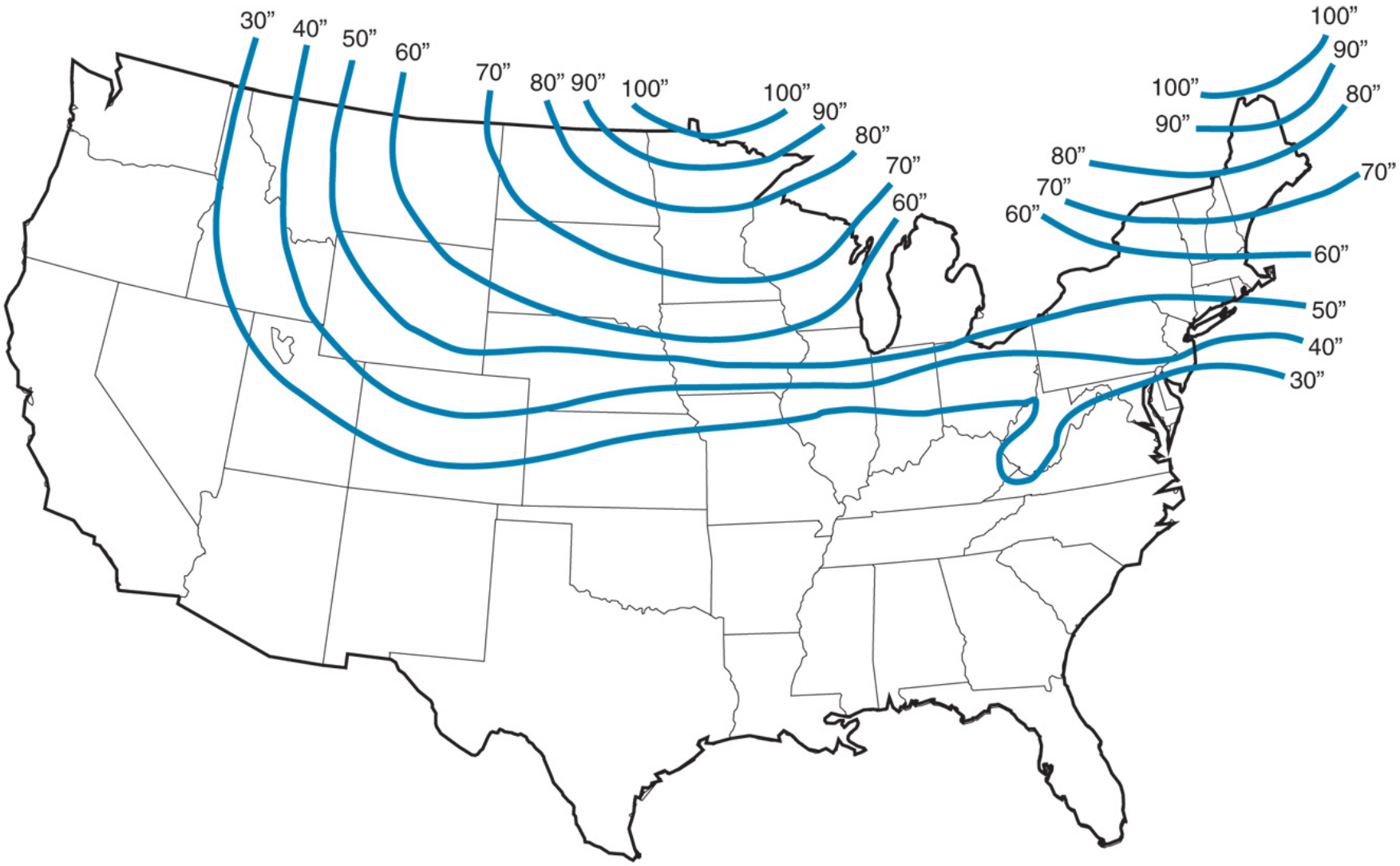

RIPCORD
Split Release


ZIPsystem

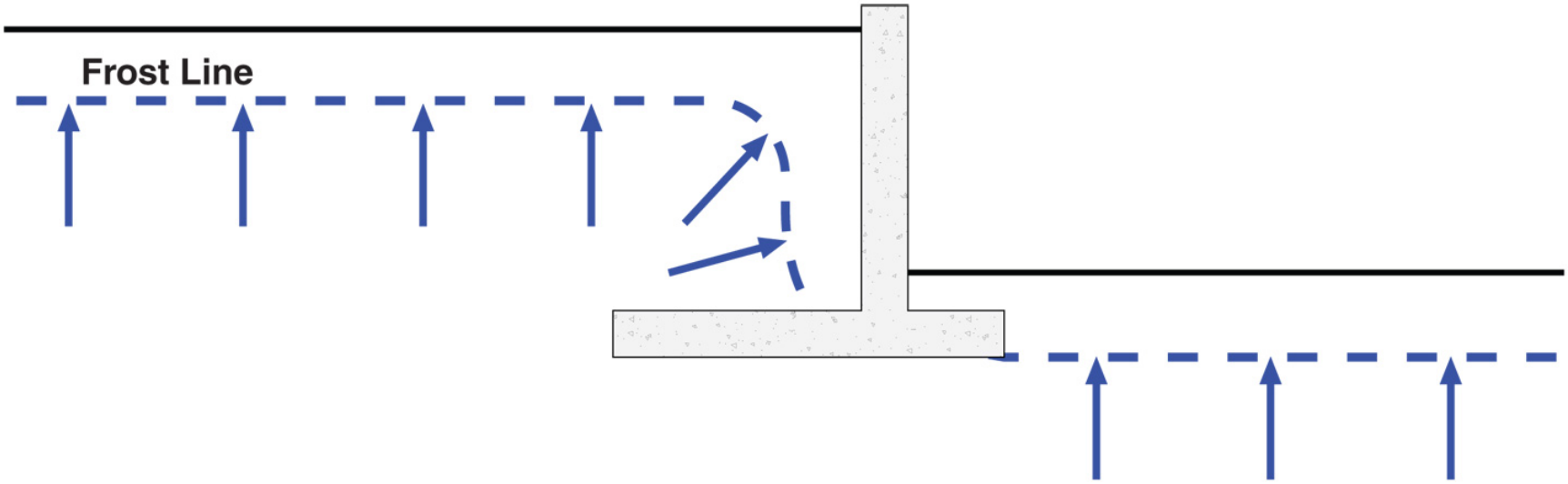

ZIPsystem

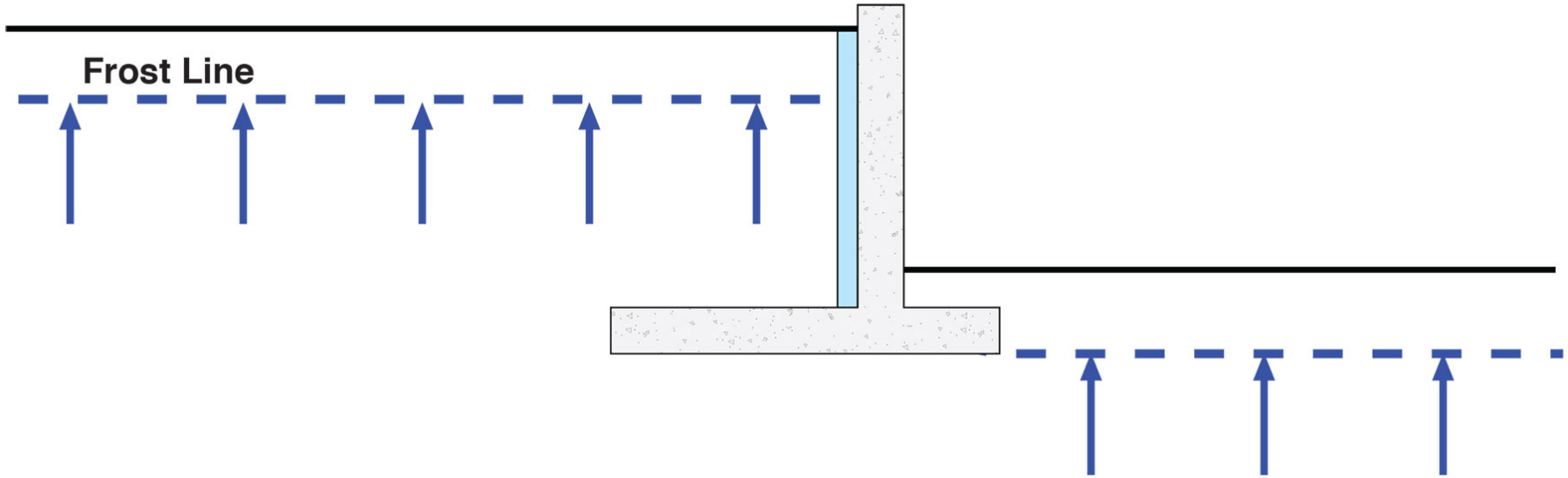

ZIP system
ZIP system
ZIP system
ZIP system

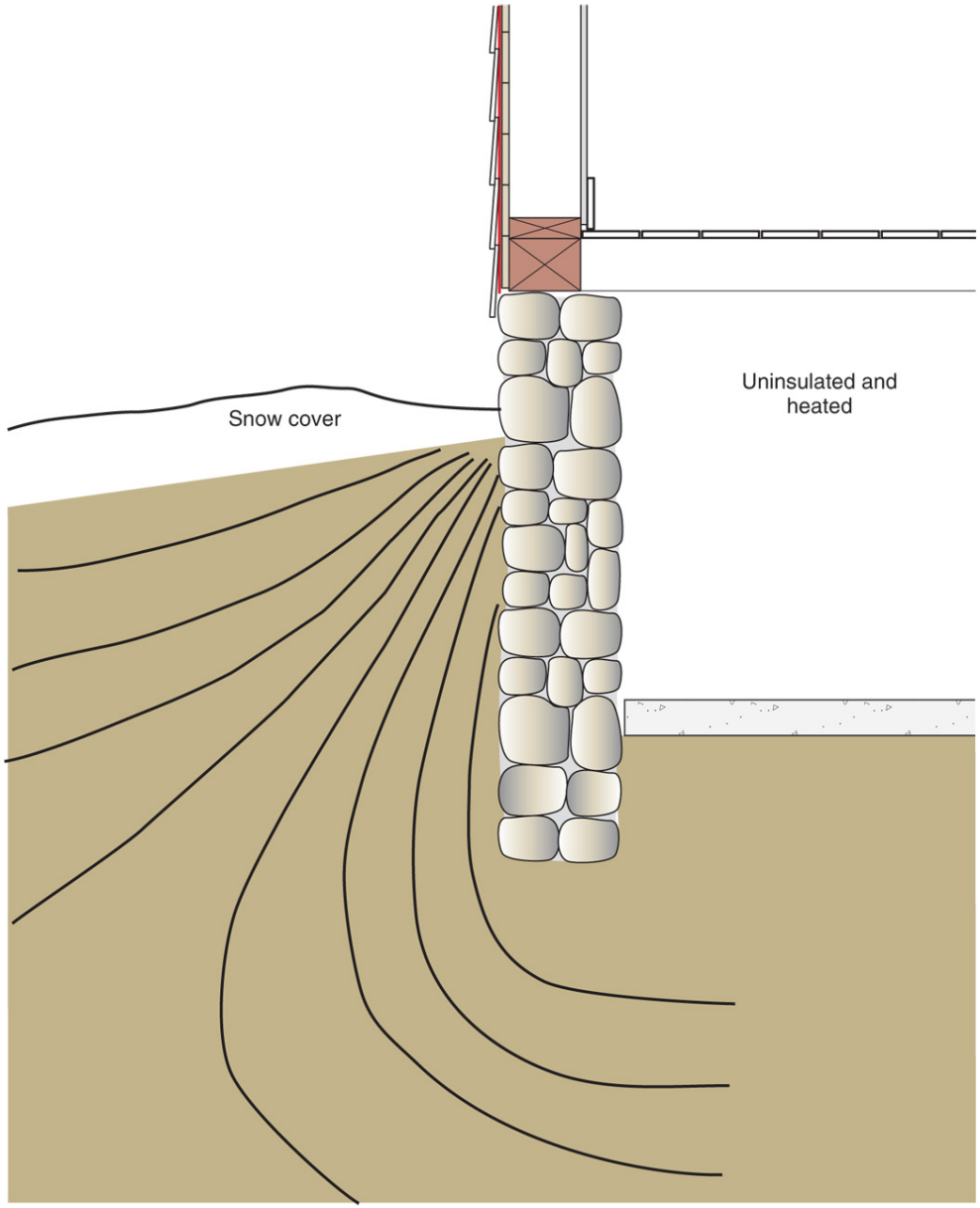

ZIPsystem
ZIPsystem
ZIPsystem
ZIPsystem
ZIPsystem
GRACE VYCOR PLUS
GRACE VYCOR PLUS

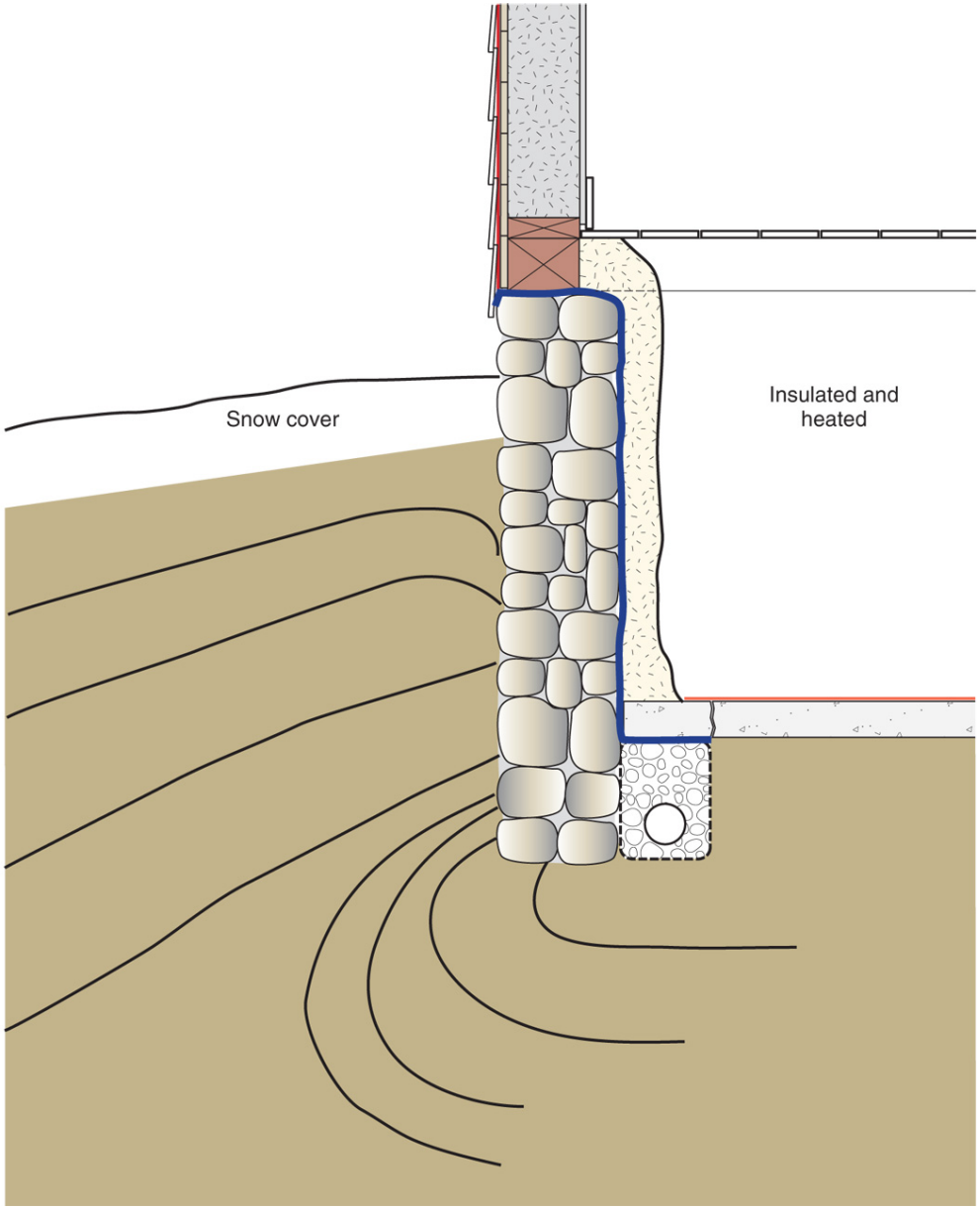


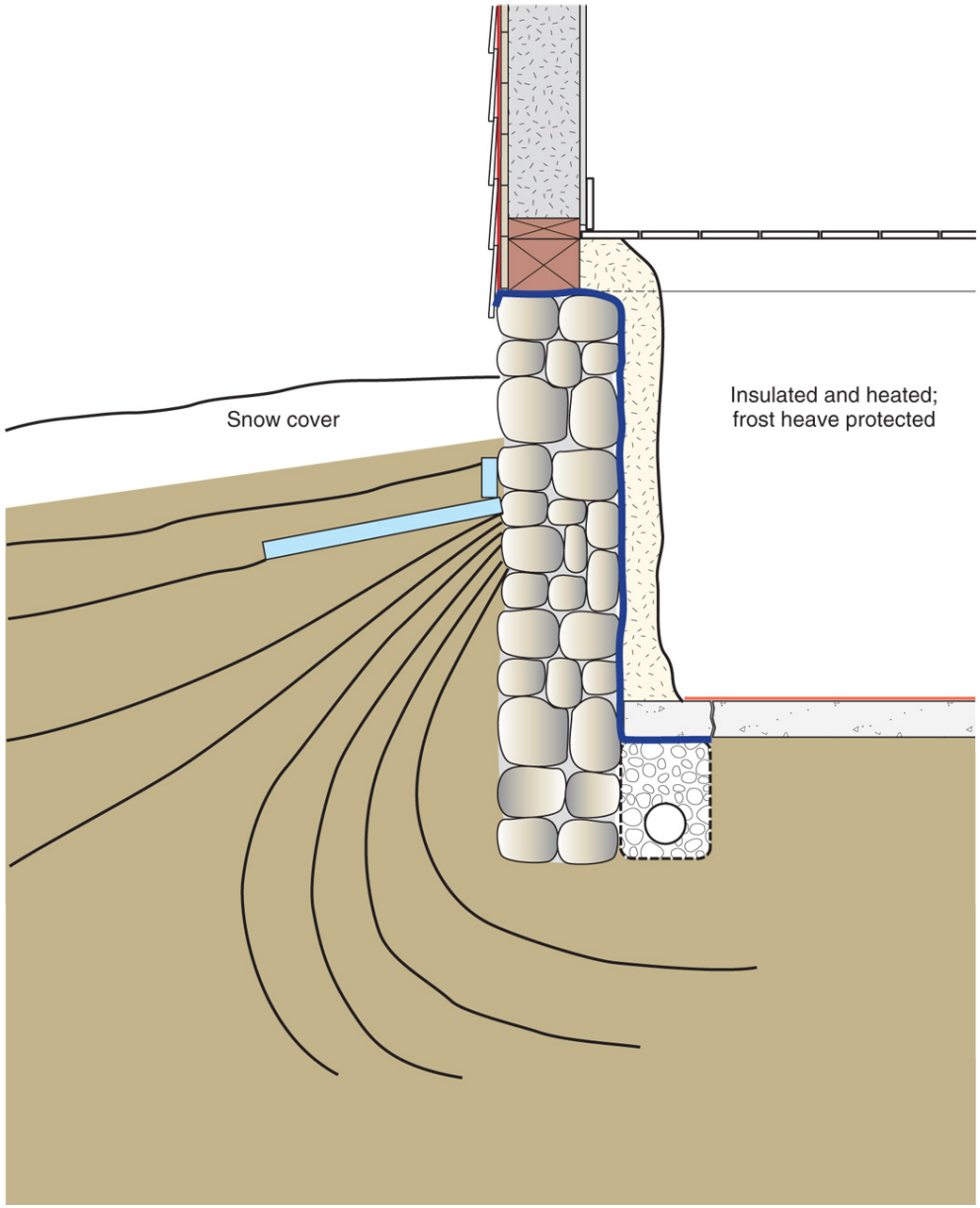
From the US Army Corps Engineers Extreme Frost Penetration
(in inches) based on state averages.

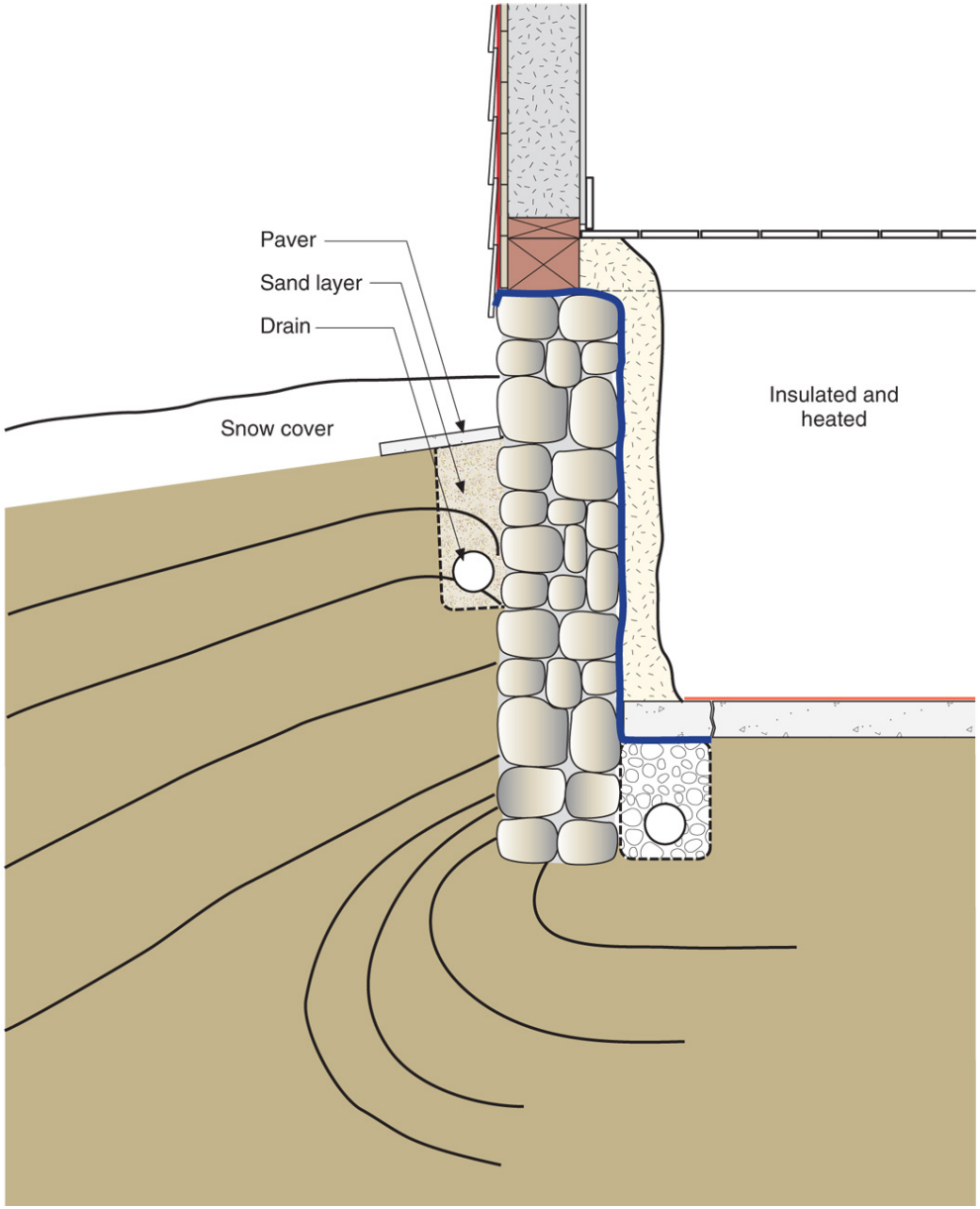

Frost Line

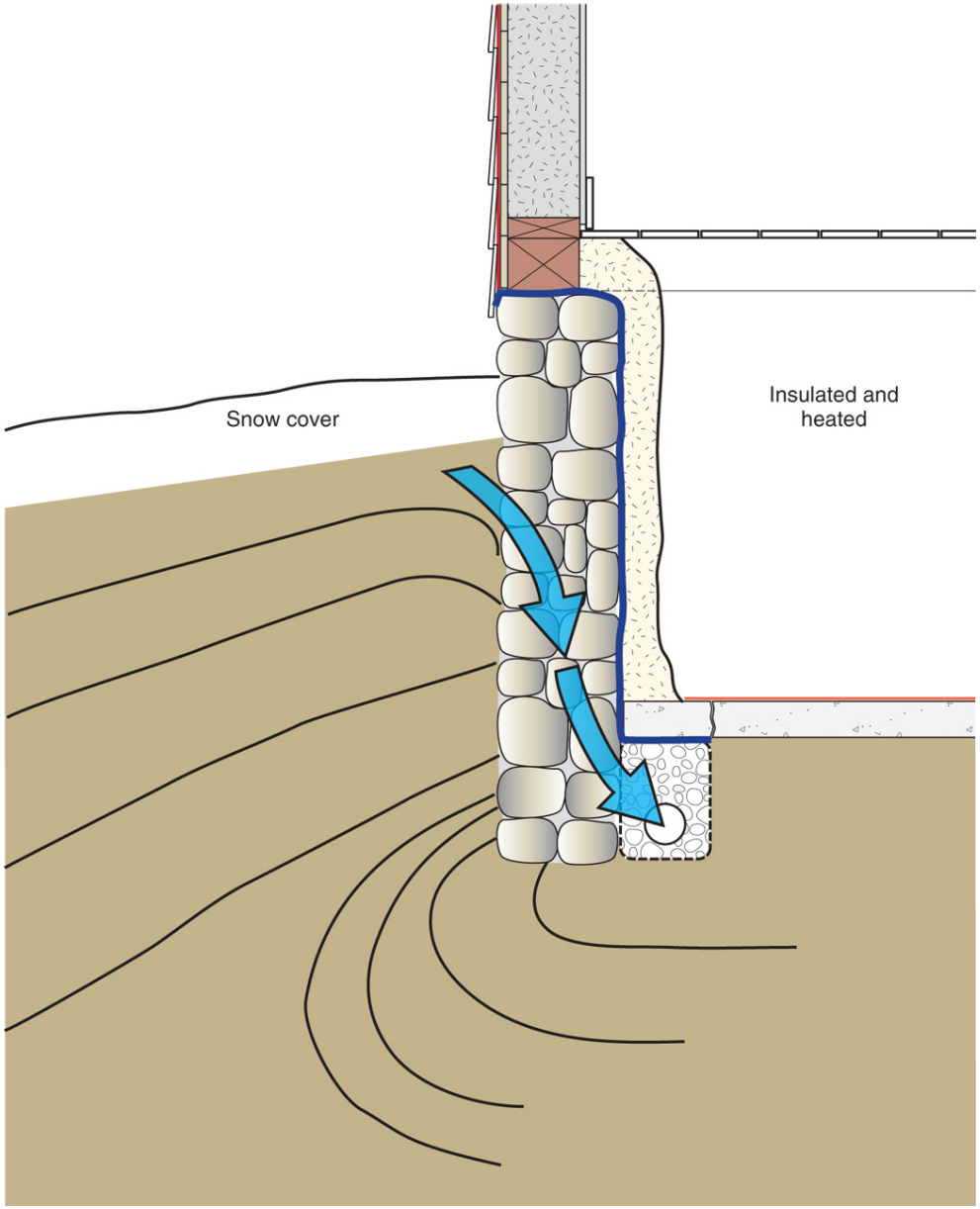

Frost Line


Snow cover
Uninsulated and
heated


Snow cover
Insulated and
heated

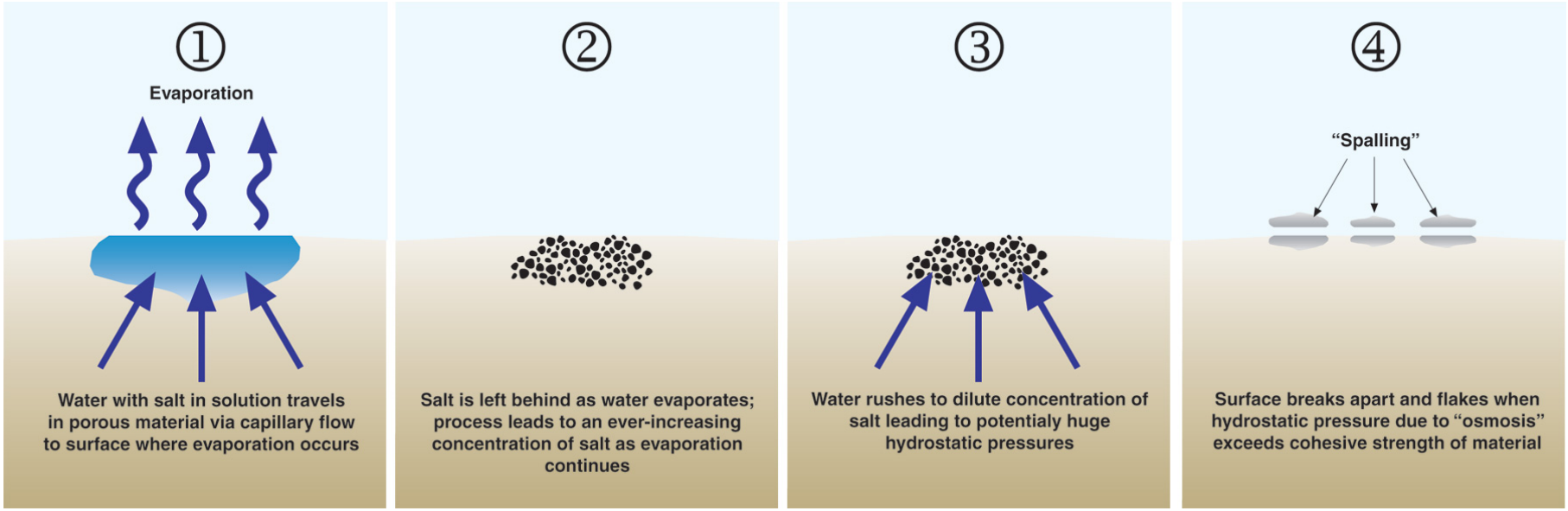

Snow cover
Insulated and heated;
frost heave protected


Paver
Sand layer
Drain
Snow cover
Insulated and
heated


Snow cover
Insulated and
heated

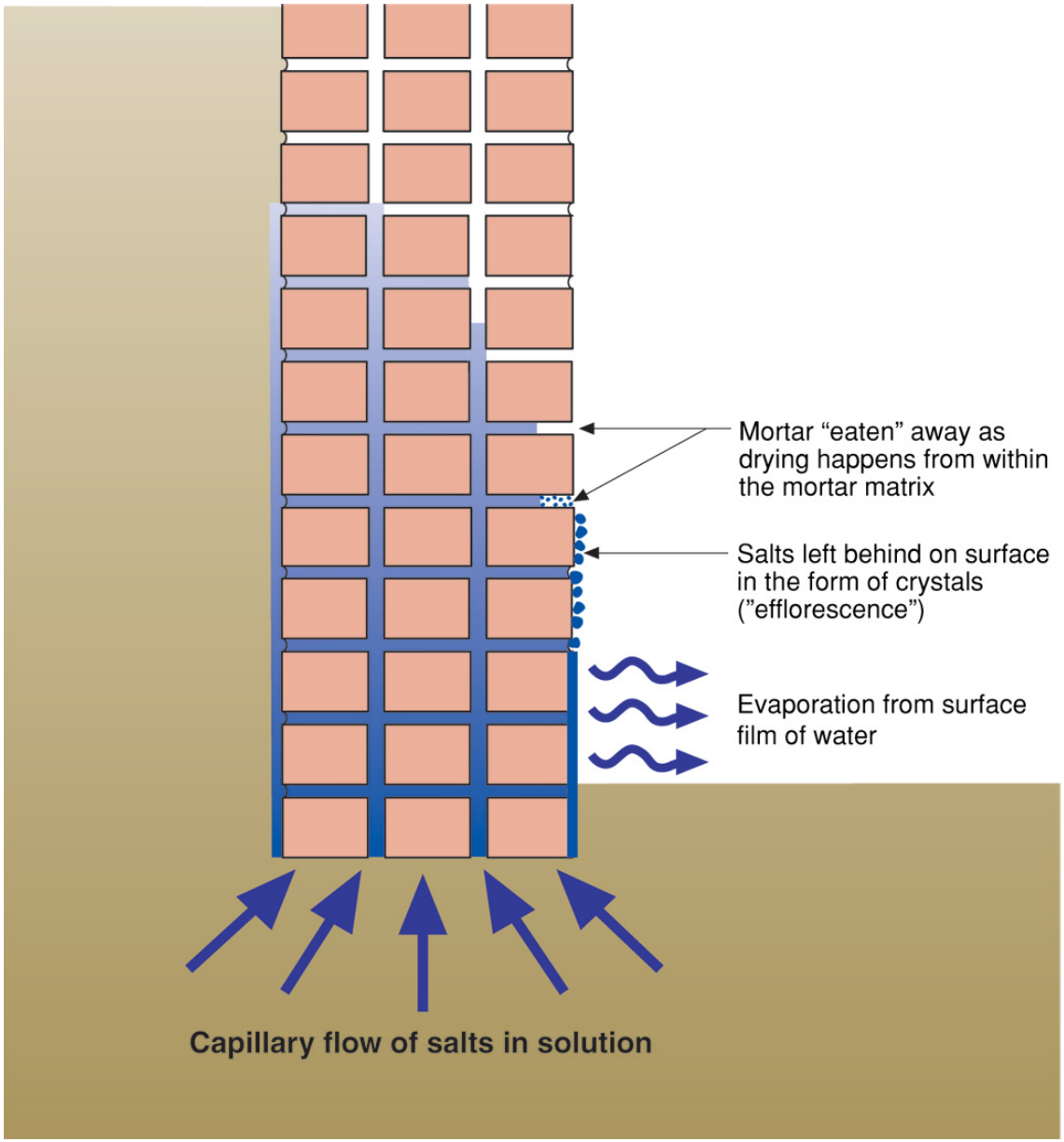
Capillarity + Salt = Osmosis

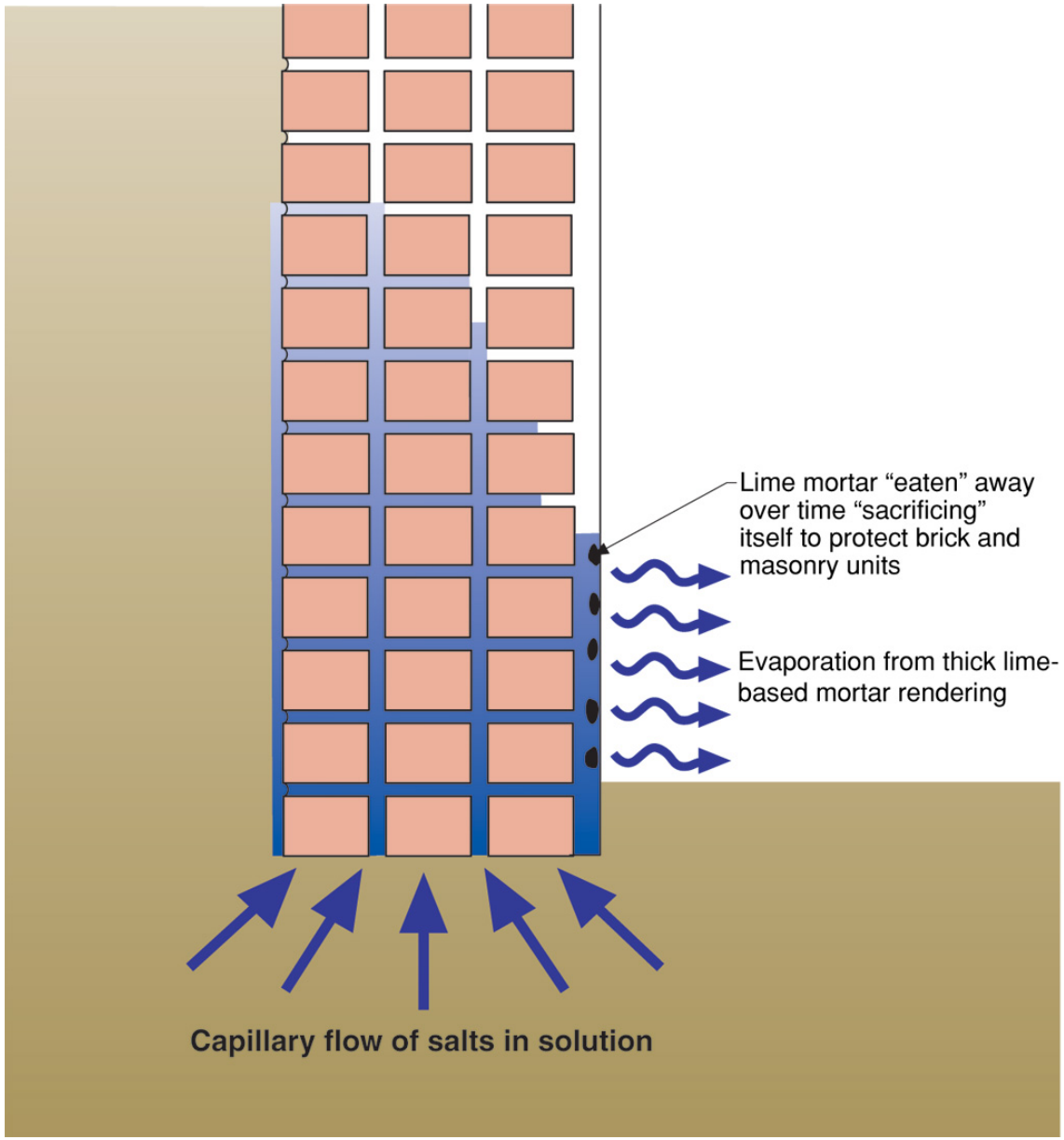
- Mineral salts carried in solution by capillary water
- When water evaporates from a surface the salts left behind form crystals in process called efflorescence
- When water evaporated beneath a surface the salts crystallize within the pore structure of the material in called sub-efflorescence
- The salt crystallization causes expansive forces that can exceed the cohesive strength of the material leading to spalling


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 potentialy huge hydrostatic pressures
④
"Spalling"
Surface breaks apart and flakes when hydrostatic pressure due to "osmosis" exceeds cohesive strength of material

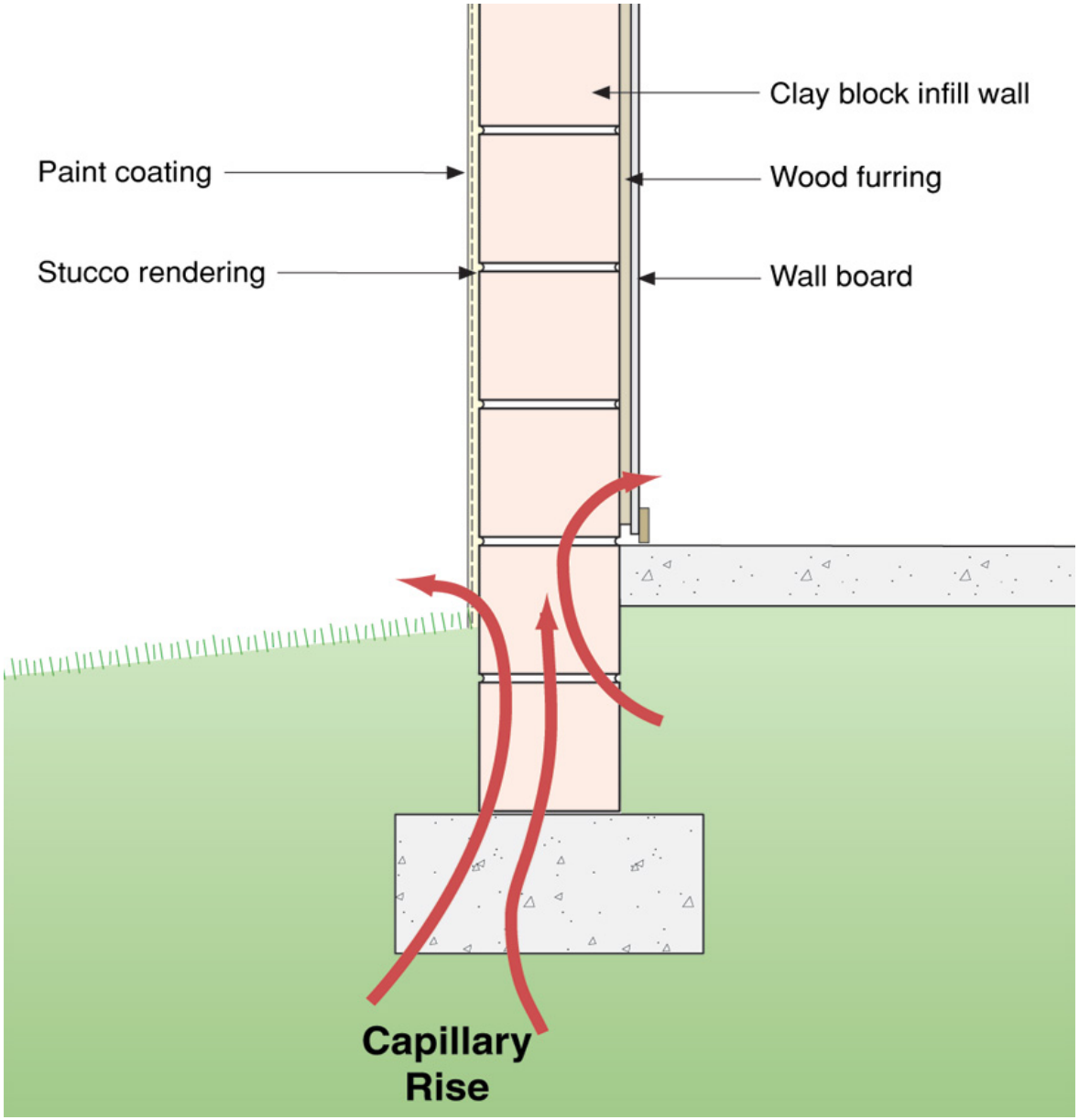
Diffusion + Capillarity + Osmosis = Problem

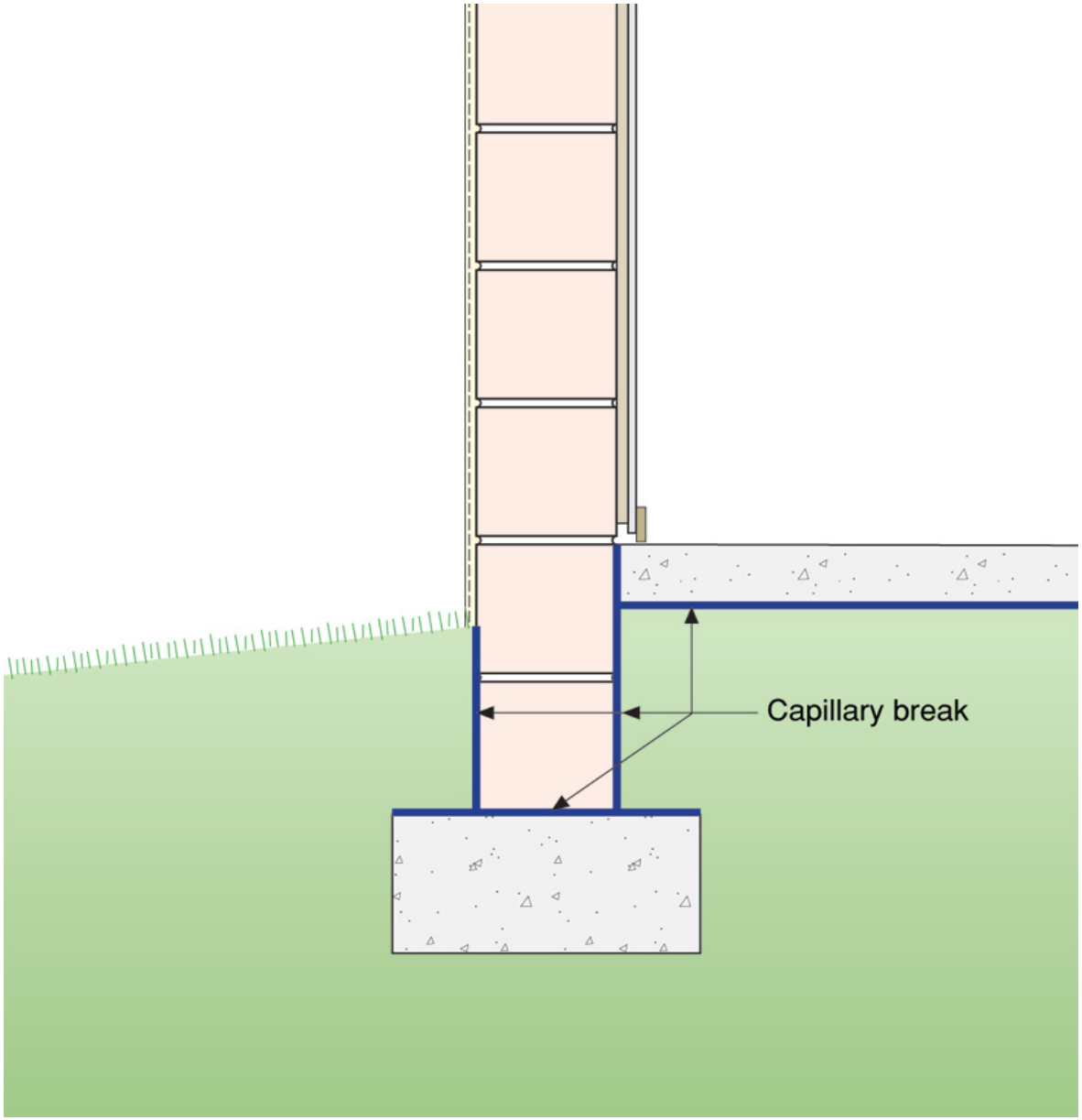
- Diffusion Vapor Pressure 3 to 5 psi
- Capillary Pressure 300 to 500 psi
- Osmosis Pressure 3,000 to 5,000 psi

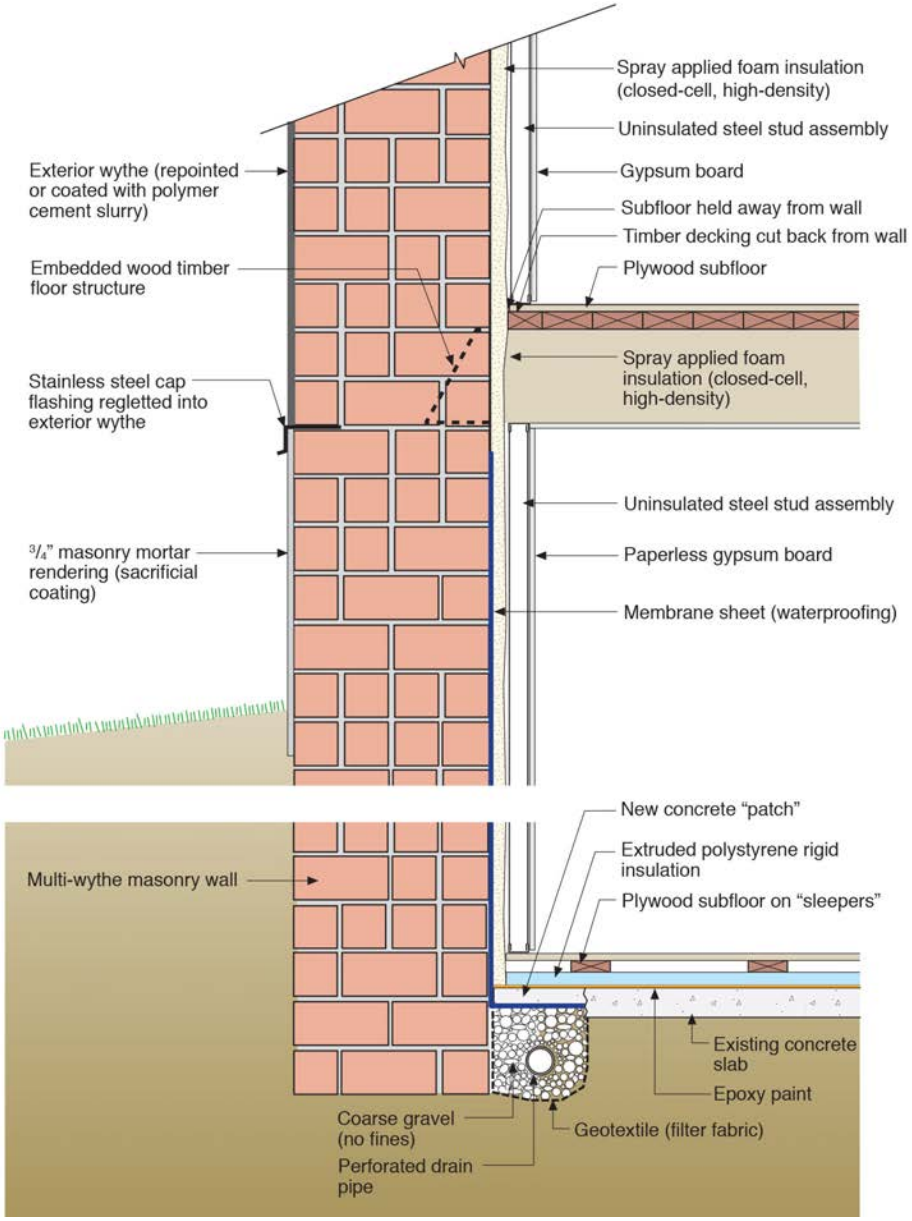

Mortar “eaten” away as drying happens from within the mortar matrix
Salts left behind on surface in the form of crystals (”efflorescence”)
Evaporation from surface film of water
Capillary flow of salts in solution

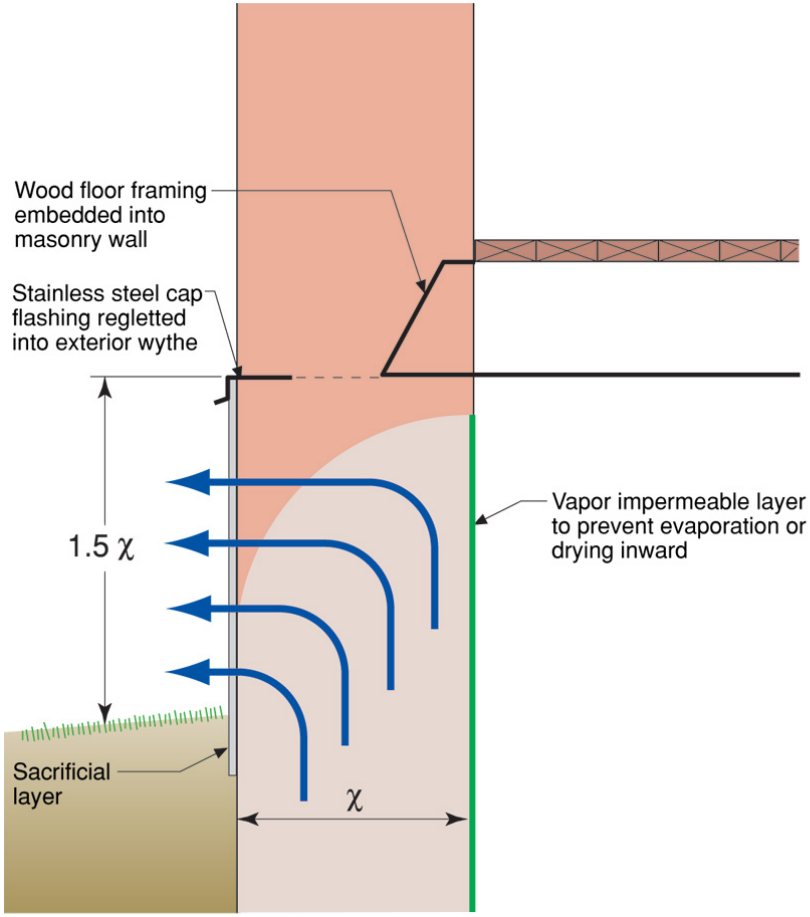

Lime mortar “eaten” away over time “sacrificing” itself to protect brick and masonry units
Evaporation from thick lime-based mortar rendering
Capillary flow of salts in solution

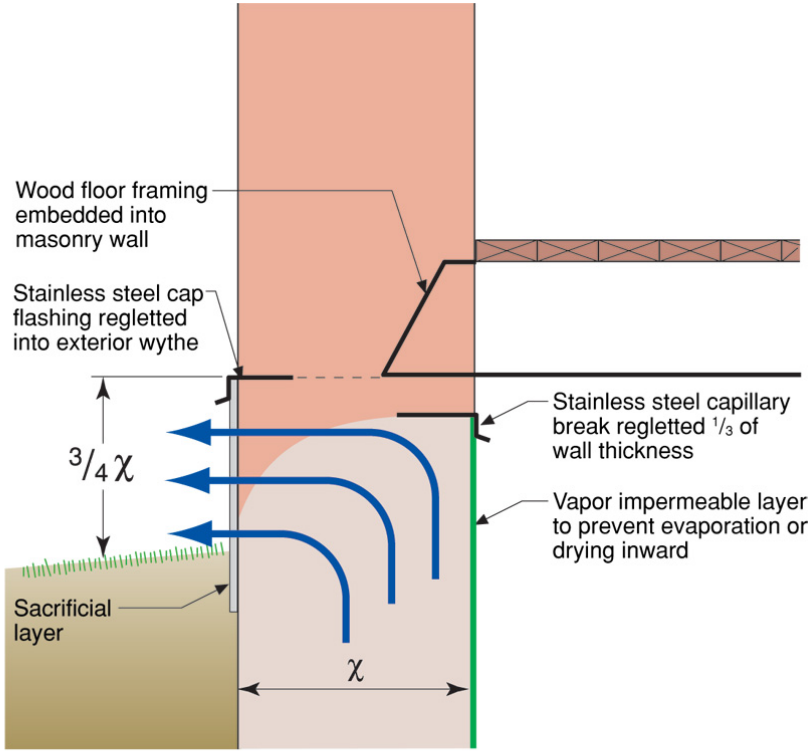

35


Clay block infill wall
Paint coating
Wood furring
Stucco rendering
Wall board
Capillary
Rise

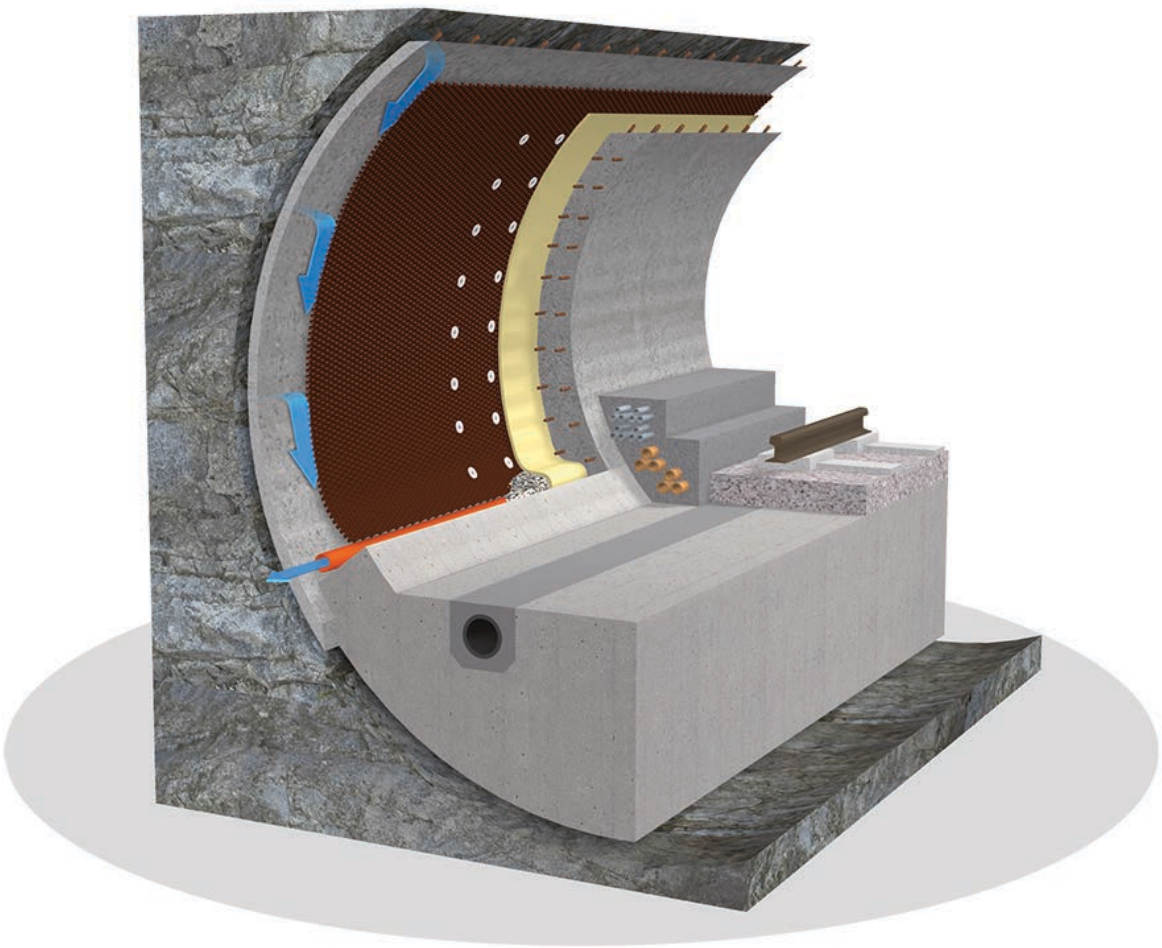

Capillary break


Spray applied foam insulation (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)
Embedded wood timber floor structure
Spray applied foam insulation (closed-cell, high-density)
Stainless steel cap flashing regletted into exterior wythe
Uninsulated steel stud assembly
3/4" masonry mortar rendering (sacrificial coating)
Paperless gypsum board
Membrane sheet (waterproofing)
New concrete "patch"
Extruded polystyrene rigid insulation
Plywood subfloor on "sleepers"
Multi-wythe masonry wall
Existing concrete slab
Epoxy paint
Coarse gravel (no fines)
Geotextile (filter fabric)
Perforated drain pipe


Wood floor framing embedded into masonry wall
Stainless steel cap flashing regletted into exterior wythe
1.5 χ
Vapor impermeable layer to prevent evaporation or drying inward
Sacrificial layer
χ


Wood floor framing embedded into masonry wall
Stainless steel cap flashing regletted into exterior wythe
3/4 χ
Stainless steel capillary break regletted 1/3 of wall thickness
Vapor impermeable layer to prevent evaporation or drying inward
Sacrificial layer
χ


EURO
TUNNEL




STONE SLINGER
MACK
DELTA-MS
DELTA-MS
DELTA-MS
DELTA-MS


EXITS 24B-A
1A

16 Million Gallons are Pumped Out of the Tunnels Each Year….