CHAPTER 6

Footings, Foundation Walls, Basements, and Slabs

Most residential construction today is supported on either concrete slabs-on-grade or on concrete or masonry foundations. There are a number of different foundation types, each of which must provide both the strength and stability to support the weight of the structure, its contents and occupants, as well as wind and snow loads that are transferred to the foundation by the structure.

6.1 Building Code Requirements

Most jurisdictions prescribe minimum building code requirements for the construction of residential foundations. The following basic requirements from the CABO *One and Two Family Dwelling Code* are fairly representative of those found in many municipalities.

- Fill material which supports footings and foundations must be designed, installed, and tested in accordance with accepted engineering practice.
- The grade away from foundation walls must fall a minimum of 6 in. within the first 10 ft. Where lot lines, walls, slopes, or other physical barriers prohibit the minimum slope, drains or swales must be provided to ensure drainage away from the structure.

- In areas likely to have expansive, compressible, or shifting soils or other unknown soil characteristics, the building official may require a soil test by an approved agency to determine soil characteristics at a particular location.
- When topsoils or subsoils are expansive, compressible, or shifting, they must be removed to a depth and width sufficient to assure stable moisture content in each bearing area or stabilized within each bearing area by chemical treatment, dewatering, or presaturation. Unstable soils that are removed may not be used as fill in other areas.
- Concrete must have a minimum compressive strength as shown in Figure 6-1.

6.1.1 Soil-Bearing Pressures

The soil which supports building foundations must be strong enough to withstand the loads that are applied to it. The Code provides that in lieu of a complete soils evaluation to determine bearing characteristics, the values in Figure 6-2 may be assumed. If you do not know what type of soil exists on a given site, the building official should be able to tell you what the code requirements are. You'll need to know what the soil bearing capacity is to determine minimum footing dimensions.

6.1.2 Frost Depth

The water in soil freezes and expands, then contracts again when it thaws. This phenomenon is called *frost heave.* Footings and foundations must be set below the winter frost line to avoid damage from frost heave. The depth to which the soil freezes depends not only on climate and geographic location, but also on soil composition, altitude, and weather patterns. The map in Figure 6-3 shows long lines of equal frost depth in the central and southern states, but in the west and north shows local frost depths that can vary widely within a small area. Along the Gulf coast, the frost depth is only 1 in., but in northern Maine a footing must be set 6 ft. deep to reach below the frost line.

6.2 Footings

Foundation walls can bear directly on the subsoil when the soil has a high bearing capacity. If the soil bearing capacity is lower, the wall

Type or location of concrete	Minimum Specified Compressive Strength — Weathering Potential*		
	Negligible	Moderate	Severe
Basement walls and foundations not exposed to weather	2,500	2,500	2,500‡
Basement slabs and interior slabs on grade, except garage floor slabs	2,500	2,500	2,500‡
Basement walls, foundation walls, exterior walls and other vertical concrete work exposed to weather	2,500	3,000†	3,000†
Porches, carport slabs and steps exposed to weather, and garage slabs	2,500	3,000†§	3,500†§

*See map for weathering potential (Alaska and Hawaii are classified as severe and negligible, respectively).

†Use air-entrained cement.

‡Use air-entrained cement if concrete will be subject to freezing and thawing during construction.

§Minimum cement content 5-½ bags per cubic yard.

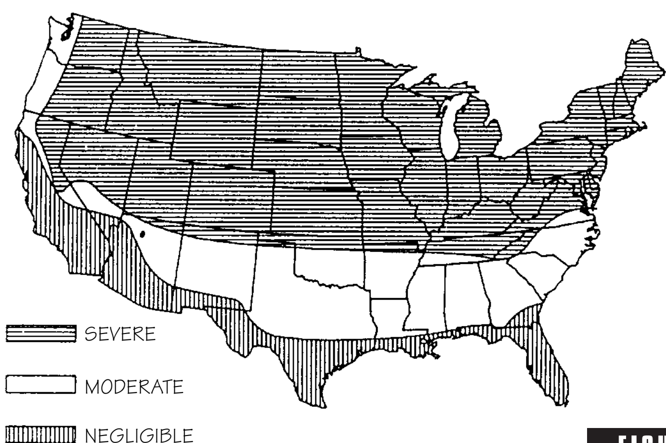


FIGURE 6-1

Minimum required strength of concrete for footings, slabs, and foundations. ***(from Council of American Building Officials*** **One and Two-Family Dwelling Code,** ***Falls Church, VA).***

Class of Material	Soil-Bearing Pressure, psf
Crystalline bedrock	12,000
Sedimentary rock	6,000
Sandy gravel or gravel	5,000
Sand, silty sand, clayey sand, silty gravel, and clayey gravel	3,000
Clay, sandy clay, silty clay, and clayey silt	2,000

FIGURE 6-2

Allowable bearing pressures for various types of soil. *(from Council of American Building Officials,* One and Two-Family Dwelling Code, *Falls Church, VA)*.

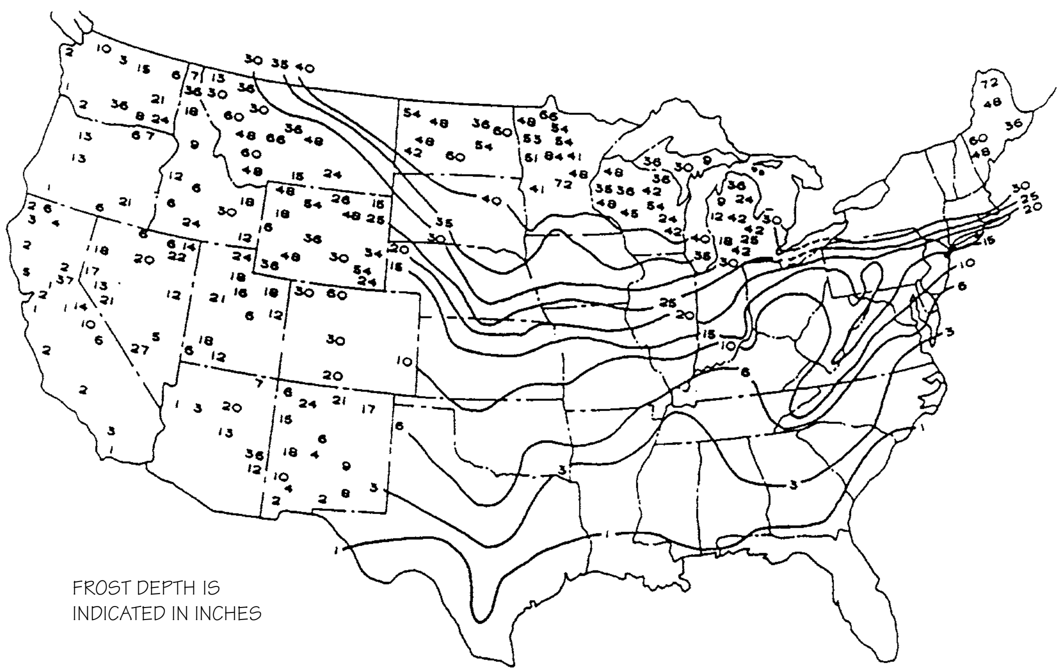


FIGURE 6-3

Average annual frost depth for continental United States. *(from* Architectural Graphic Standards, *9th ed.)*.

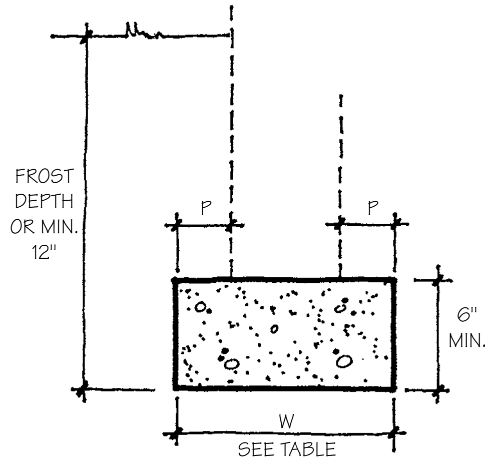
may require a concrete footing that is wider than the wall itself and capable of distributing the weight of the structure over a larger area.

6.2.1 Concrete Footings

Concrete footings are used to support building walls, freestanding garden walls, and retaining walls for many types of construction. Footings that are wider than the walls they support are typically called *spread footings.* The Code requires that footings be:

- A minimum of 6 in. thick
- Supported on undisturbed natural soil or on engineered fill
- Set below the frost line unless otherwise protected against frost heave
- A minimum of 12 in. below grade regardless of frost depth

The required footing width (W) is based on the bearing capacity of the soil as indicated in Figure 6-4. Footing projections (P) on either side of the foundation wall must be a minimum of 2 in., but not more than the footing thickness. For a soil with moderate bearing capacity of 3,000 psf, in a conventionally framed 2-story house, the minimum required footing width is only 10 in. Soil with a relatively low bearing capacity of 2,000 psf, supporting a 2-story home of brick veneer over wood frame construction would require a footing 19 in. wide. The lower the soil-bearing capacity, the wider the footing required to spread the building's weight over a larger soil area. The footing widths shown in the tables are *minimum* dimensions. The wider the footing, the more stable it will be against overturning, rocking, or uneven settlement in any soil. Many industry professionals recommend using a rule of thumb which says that the footing thickness should be the same as the width of the foundation wall it supports, and the footing width should be a minimum of two times the thickness of the foundation wall it supports. For an 8-in. concrete block wall, this would mean a 16-in.-wide footing, 8 in. thick. The soil-bearing capacity may require a minimum footing width greater than or less than the rule of thumb, so the actual width should always be the larger of the two (Figure 6-5). In soils with high bearing capacity where the minimum required footing width is 8 in. or less, the foundation wall can be safely and economically constructed to bear directly on the subsoil without a spread footing. Once the width exceeds 8 in., it is usually more economical to build a spread footing than to unnecessarily increase the thickness of



MINIMUM WIDTH (W) OF CONCRETE FOOTINGS, IN.

	Loadbearing Value of Soil, psf					
	1,500	2,000	2,500	3,000	3,500	4,000
Conventional Wood Frame Construction						
1 story	16	12	10	8	7	6
2 story	19	15	12	10	8	7
3 story	22	17	14	11	10	9
4-Inch brick veneer over wood frame or 8-inch hollow concrete masonry						
1 story	19	15	12	10	8	7
2 story	25	19	15	13	11	10
3 story	31	23	19	16	13	12
8-inch solid or fully grouted masonry						
1 story	22	17	13	11	10	9
2 story	31	23	19	16	13	12
3 story	40	30	24	20	17	15

FIGURE 6-4

Minimum requirements for concrete footings. ***(from Council of American Building Officials* One and Two-Family Dwelling Code, *Falls Church, VA)*.**

the entire foundation wall, especially if its height is more than a foot or two.

For footings 12 in. or less in thickness, formwork is easiest to build of 2 × lumber because there is less cutting required than for making short plywood forms. Remember that the actual size of the lumber is 1/2 in. less than its nominal dimension. Using 2 × 6s for a 6-in.-thick footing, for example, requires that the boards be set slightly off the ground to achieve the required dimension. To keep the concrete from running out the bottom of the forms, backfill with a little soil after the forms and braces are in place (Figure 6-6). If a footing is 8 in. or more in thickness, use 1 × 4 *spreaders* spaced about 4 ft. apart along the top of the forms to keep the concrete from bowing them out of shape (Figure 6-7). A beveled 2 × 4 should be inserted lengthwise along the top of the footing to form a *keyway* which will keep the wall from sliding. The keyway form should be well oiled so that it will be easy to remove after the concrete has hardened. Concrete walls set on top the footing will interlock physically along the indentation. The bottom course of a masonry wall should be set in a full bed of mortar which will also interlock slightly to prevent sliding.

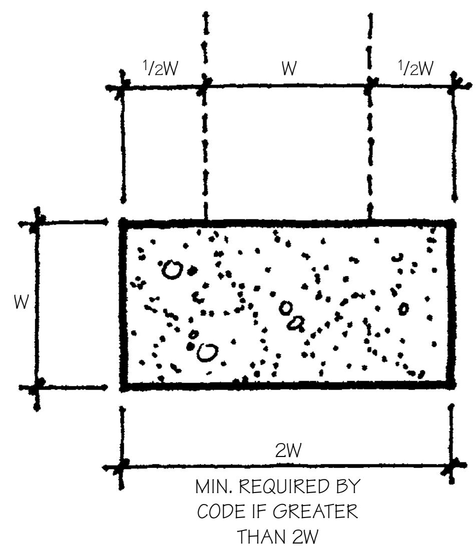


FIGURE 6-5

Rule-of-thumb footing size requirements.

6.2.2 Stepped Footings

Where the ground under a wall slopes slightly, you can build a footing that is level but is deeper in the ground at one end than the other. Where the ground slopes more steeply, though, it is best to step the form down the slope so that the footing is in a series of level sections (Figure 6-8). For footings with lumber forms, build two overlapping forms to create the change in height (Figure 6-9), making sure that the overlapping portion is at least as long as the footing is thick. That is, for an 8-in.-thick footing, overlap the two adjoining levels at least 8 in.

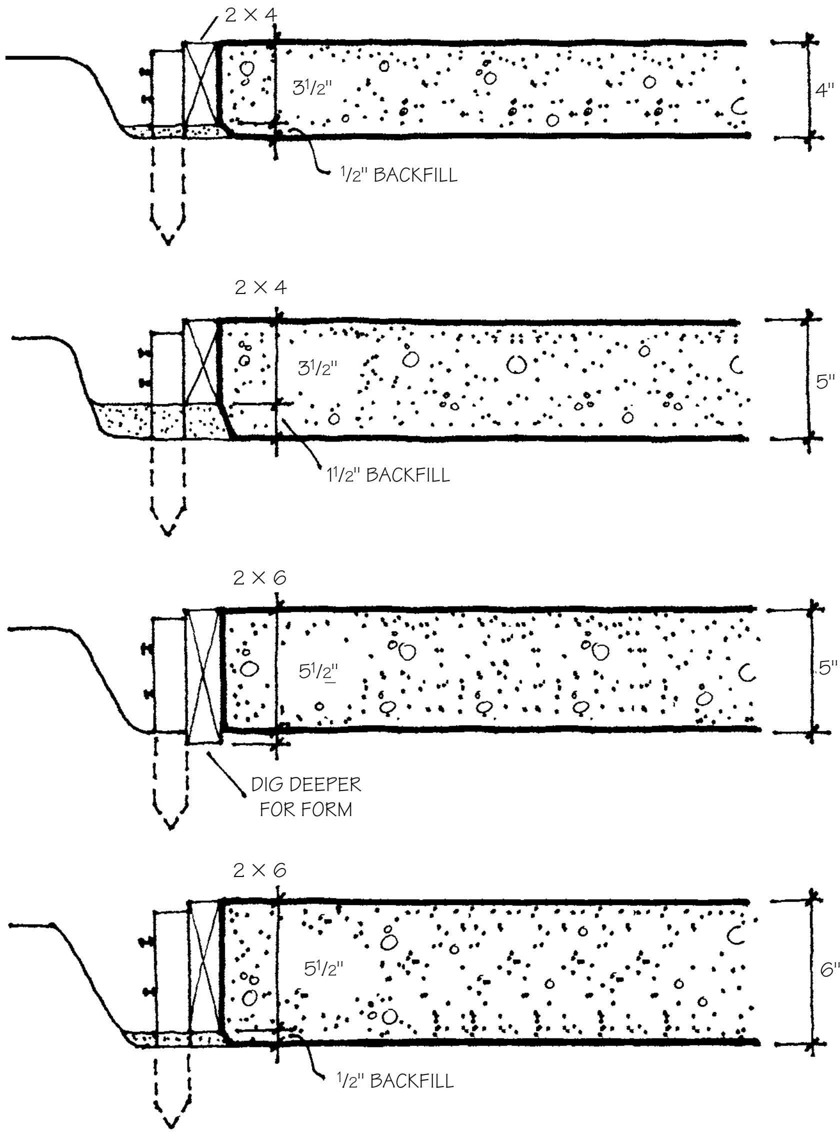


FIGURE 6-6

Backfill at bottom of concrete forms.

6.2.3 Footings Without Forms

For shallow footings in firm soil, wood forms can be eliminated and the concrete formed by the earth trench itself. The trench should be the exact width of the footing, excavated using a square-nosed shovel to keep the edges straight. The trench should be deep enough that the bottom of the footing will be at least 12 in. below grade as required by Code (Figure 6-10). A row of wooden stakes or short reinforcing bar lengths driven into the ground down the middle is used to indicate the required thickness of the concrete. A straight 2 × 4 and a level can be used to make sure the tops of the guide stakes are level. When the concrete is poured, simply strike and float the surface even with the tops of the stakes and then remove them. A

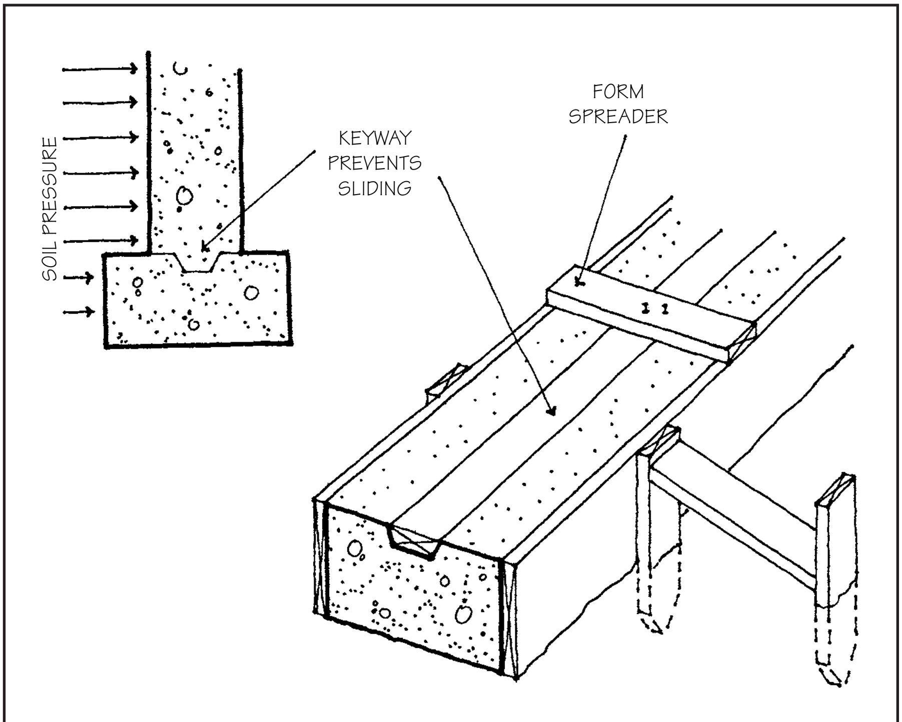


FIGURE 6-7

Footing spreaders and keyways. ***(from Portland Cement Association,*** **The Homeowner's Guide to Building with Concrete, Brick and Stone,** ***PCA, Skokie, Illinois)*.**

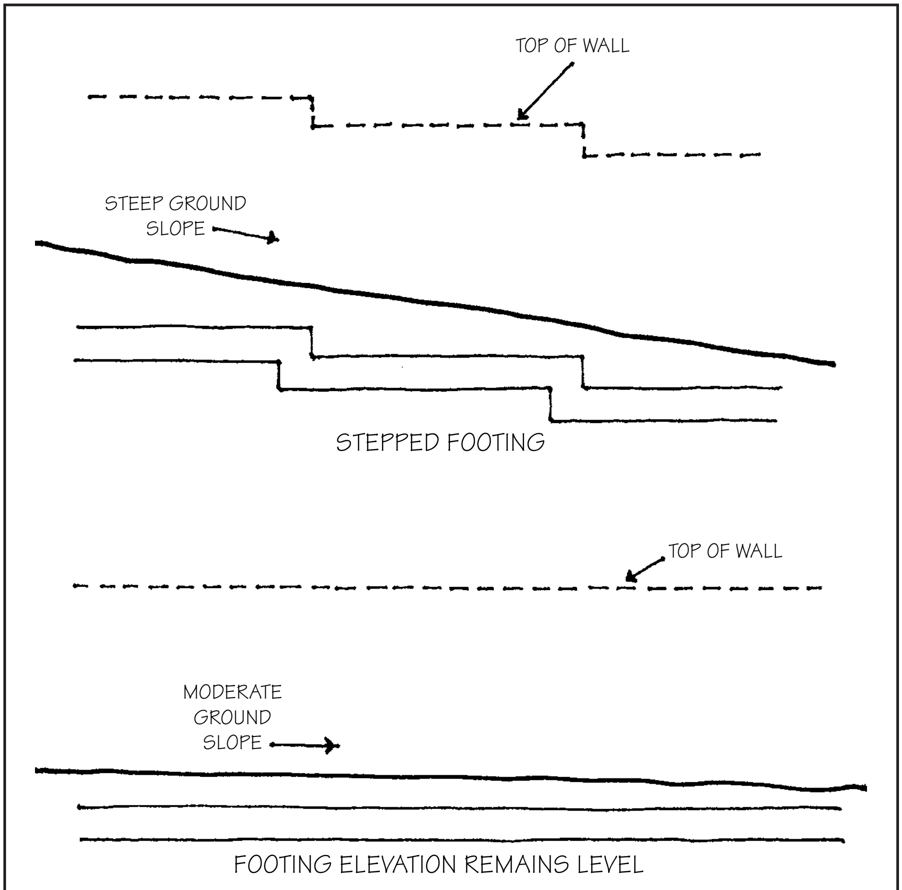


FIGURE 6-8

Footings on sloped ground.

concrete with a 6-in. slump will flow easily and seek its own level in the footing, but the high water-cement ratio reduces it compressive strength. Using a 6-sack mix (6 sacks of cement per cubic yard of concrete) instead of a 5 or 5 1/2-sack mix will compensate for the extra water and higher slump and still provide the 2,500 psi compressive strength required by Code. For stepped footings, step the excavation down and form a dam with a board or piece of plywood and wooden stakes driven firmly into the sides of the excavation (Figure 6-11).

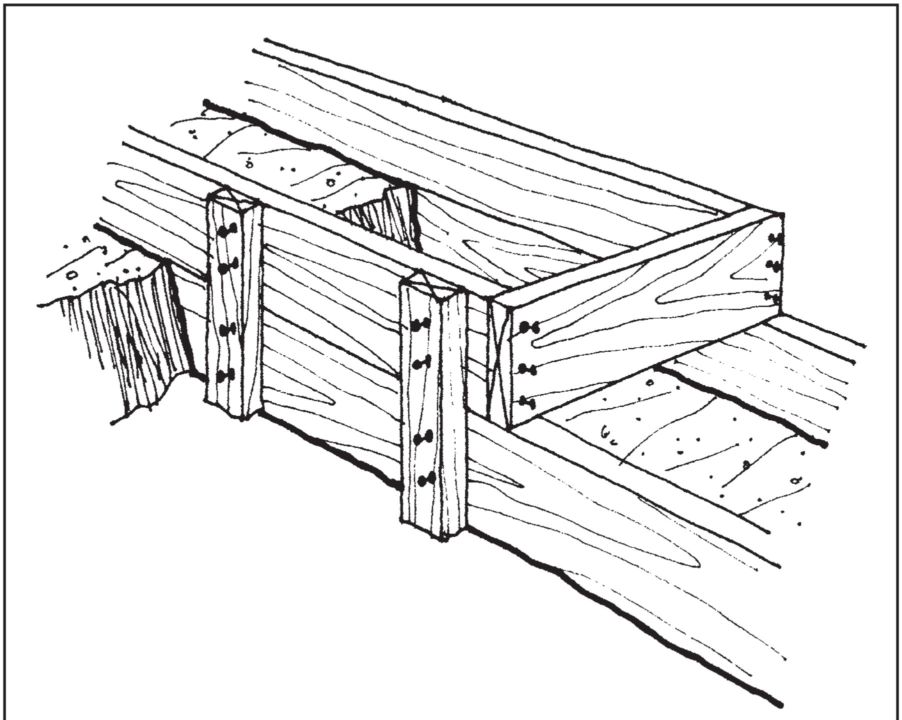


FIGURE 6-9

Stepped footing.

6.2.4 Steel Reinforcement

Footings for light loads are often built without steel reinforcing, but many footing designs require steel reinforcing bars to increase strength and help distribute heavier loads. The bars should be placed horizontally in the forms and supported off the ground in the position indicated by the drawings (bars are usually located one-third up from the bottom of the form, and at least 3 in. off the ground). If the footing is to support a reinforced concrete or masonry wall, it will also require short sections of reinforcing bar *dowels* that turn up and can be tied to the vertical reinforcement in the wall. The horizontal leg of the dowel should be at least 12 in. long, and the vertical leg at least 18 in. tall so that it will overlap horizontal reinforcing bars in the footing and vertical reinforcing bars in the wall a

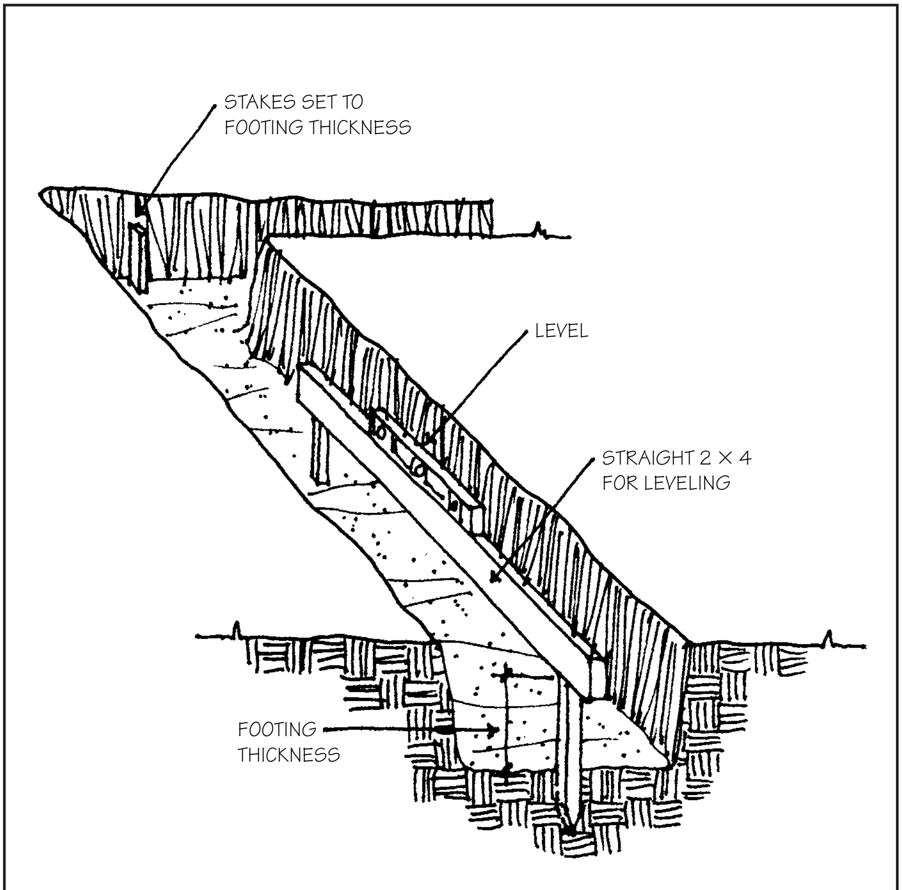


FIGURE 6-10

Trenched footing without forms.

minimum of 12 in. or 30 times the diameter of the bars (Figure 6-12). For foundation walls that are unreinforced, dowels can be used to tie the footing and wall together instead of forming a keyway. If the footing does not contain horizontal reinforcing bars, the dowels can be tied to the spreaders on top of the footing forms to hold them in place until the concrete hardens. Make sure the dowel spacing is accurate, especially if the bars will have to align with the hollow cores of a masonry unit wall. Provide a minimum distance of 1-$^{1}/_{2}$ in. between the footing reinforcement and the sides of the form, and keep the bars at least 3 in. off the ground to assure that they are fully embedded in concrete and protected from the corrosive effects of moisture in the soil. Bars can be supported on small stones or pieces of concrete block or tied to the 1 × 4 spreaders on top of the forms with a loop of twisted wire.

6.3 Foundation Walls and Basements

Basements are quite common in many parts of the country and almost unheard of in others. Where the frost line is relatively shallow and the footings are therefore close to the finish grade, only a short foundation wall (or stem wall as they are sometimes called) is needed to bring the construction above ground to provide support for the building frame. In cold climates where footings are required to be set deep in the ground to avoid frost heave, foundation walls may have to be several feet tall to reach above grade. With a little additional excavation, the footings can be set deeper and the foundation wall height extended sufficiently to accommodate construction of a habitable basement that is fully or partially below grade. The taller the foundation wall required by footing depth, the less additional work required to enclose a basement space.

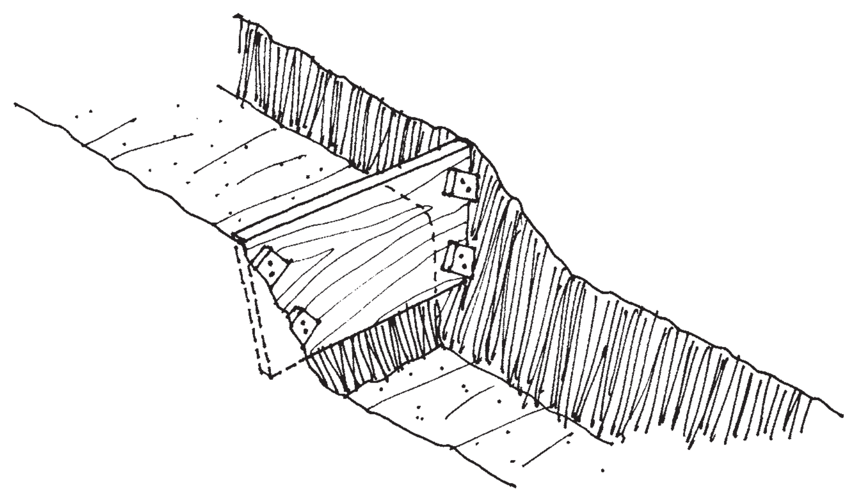


FIGURE 6-11

Stepped footing without forms.

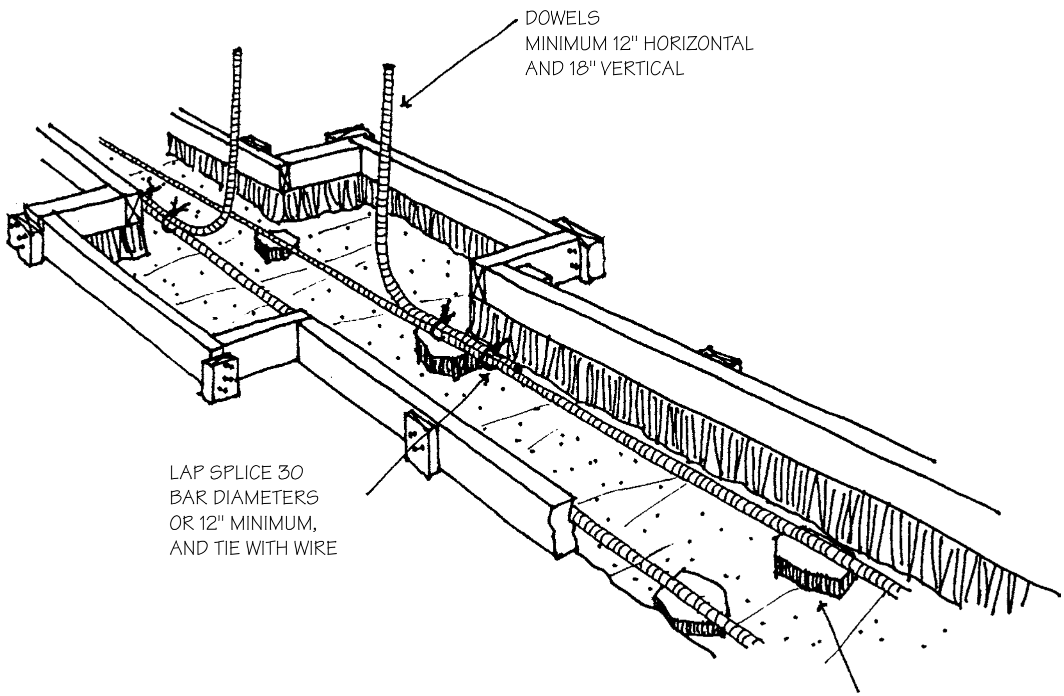


FIGURE 6-12

Footing dowels.

6.3.1 Foundation Walls

Excavations for foundation walls may be done in one of two ways. If the foundation wall will be only a foot or two in height, the footing and the wall may be built in a trench that outlines the perimeter of the building and then backfilled from both sides. If the footing must be deeper because of the frost depth, it is often expedient to excavate the entire "footprint" of the building using heavy equipment. The wall is then backfilled from the outside only, leaving a crawl space on the inside of the wall. Walls that are backfilled on both sides are very stable because the soil pressures are balanced and help the wall to resist buckling from vertical loads. Tall walls that are backfilled on only one side must resist significant lateral loads from the unbalanced backfill. Trench excavations for short walls and crawl space excavations for taller walls can be roughly marked on the ground with a sack of mason's lime so the backhoe operator can see where to dig. The excavations should be wide enough to allow plenty of room for erecting the forms, with the sides sloped generously to prevent cave-ins.

Foundation walls are typically built of concrete or masonry. Masonry foundation walls can be constructed of brick or concrete block, but are usually built of block for its economy and because its utilitarian appearance is not typically exposed to view. Foundation walls must be strong enough to support the weight of the building superstructure and resist the lateral loads of the adjacent soil. They must also be durable enough to withstand years of exposure to moisture in the soil. Foundation walls may be unreinforced or *plain* as they are referred to in some codes, or they may be reinforced with steel bars for greater strength and load resistance. Building codes typically specify maximum height and backfill limits for unreinforced foundation walls and minimum reinforcing requirements for walls which exceed the limits for unreinforced walls.

The Code provides minimum design requirements based on the type of soil in which the foundation is built. Figure 6-13 lists soil properties according to the United States Soil Classification System, which is referenced in the Code. The minimum requirements of the CABO *One and Two Family Dwelling Code* for foundation walls include the following.

- Walls must extend a minimum of 4 in. above the adjacent finished grade where masonry veneer is used and a minimum of 6 in. elsewhere.
- The thickness of foundation walls may not be less than the thickness of the walls they support except that foundation walls of at least 8-in. nominal thickness are permitted under brick veneered frame walls and under 10-in. double-wythe masonry cavity walls as long as the total height of the wall being supported (including gables) is not more than 20 ft.
- Except for walls with less than 4 ft. of unbalanced backfill, backfilling may not begin until the foundation wall has cured to gain sufficient strength and has been anchored to the floor or sufficiently braced to prevent overturning or other damage by the backfill.

Soil Group	Classification System Symbol	Soil Description	Drainage[1]	Frost Heave Potential	Volume Change Potential Expansion[2]
Group I	GW	Well-graded gravels, gravel sand mixtures, little or no fines	Good	Low	Low
	GP	Poorly graded gravels or gravel sand mixtures, little or no fines	Good	Low	Low
	SW	Well-graded sands, gravelly sands, little or no fines	Good	Low	Low
	SP	Poorly graded sands or gravelly sands, little or no fines	Good	Low	Low
	GM	Silty gravels, gravel-sand-silt mixtures	Good	Medium	Low
	SM	Silty sand, sand-silt mixtures	Good	Medium	Low
Group II	GC	Clayey gravels, gravel-sand-clay mixtures	Medium	Medium	Low
	SC	Clayey sands, sand-clay mixture	Medium	Medium	Low
	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands, or clayey silts with slight plasticity	Medium	High	Low
	CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	Medium	Medium	Medium to Low
Group III	CH	Inorganic clays of high plasticity	Poor	Medium	High
	MH	Inorganic silts, microcaceous or diatomaceous fine sandy or silty soils, elastic silts	Poor	High	High
Group IV	OL	Organic silts and organic silty clays of low plasticity	Poor	Medium	Medium
	OH	Organic clays of medium to high plasticity, organic silts	Unsatisfactory	Medium	High
	Pt	Peat and other highly organic soils	Unsatisfactory	Medium	High

Notes:
1. The percolation rate for good drainage is over 4 in. per hour, medium drainage is 2-4 in. per hour, and poor is less than 2 in. per hour.
2. Soils with a low potential expansion have a plasticity index (PI) of zero to 15, soils with a medium potential expansion have a PI of 10 to 35, and soils with a high potential expansion have a PI greater than 20.

FIGURE 6-13

Properties of soils classified according to the Unified Soil Classification System *(from Council of American Building Officials* One and Two-Family Dwelling Code,*, Falls Church, VA)*.

- Concrete and masonry foundation walls must be constructed as set forth in Figure 6-14 or Figure 6-15 for unreinforced and reinforced walls, respectively.

Figure 6-16 shows four basic types of concrete and concrete masonry foundation walls. In areas with significant risk of earthquake, building codes typically require more stringent design standards for all types of construction, including foundations. The map in Figure 6-17 shows the seismic risk areas for the United States, with zero being the lowest risk and 4 being the highest risk. Foundation walls in Seismic Zones 3 and 4 which support more than 4 ft. of unbalanced backfill are required by Code to have a minimum nominal thickness of 8 in. and minimum reinforcement consisting of #4 vertical bars spaced a maximum of 48 in. on center, and two #4 horizontal bars located in the upper 12 in. of the wall (Figure 6-18). In concrete walls, horizontal reinforcing bars are simply tied to the vertical bars to hold them at the correct height. In masonry walls, horizontal reinforcing bars are placed in a course of bond beam units which form a continuous channel and are then grouted to bond the steel and masonry together (Figure 6-19).

The sill plate to which the floor framing will be attached must be anchored to the foundation with $^1/_2$-in.-diameter bolts spaced 6 ft. on center and not more than 12 in. from corners. The bolts must extend at least 7 in. into the concrete or masonry and have a 90° bend at the bottom. For concrete walls, the bolts can be placed into the concrete as it begins to set and develop enough stiffness to hold them in place. For concrete block walls, the cores in which anchor bolts will be located must be grouted to hold the bolts in place. To isolate the grout so that it will not flow beyond the core in which the anchor will be placed, the webs of that core should be mortared in addition to the face shells, and a piece of screen wire placed in the bed joint just below the top course (Figure 6-20). As the grout begins to stiffen, the bolt is inserted in the same way as for concrete. Make sure the bolt spacing is accurate so that it does not interfere with stud spacing, and leave the threaded end exposed sufficiently to penetrate the full thickness of the plate with allowance for a nut and washer. If the wall will have stucco or siding applied, the bolt should be located so that the plate is toward the outside of the foundation wall. If the wall will have a brick or stone veneer, the bolt should be located so that the plate is toward the inside

UNREINFORCED CONCRETE AND UNREINFORCED MASONRY FOUNDATION WALLS[1]

Max. Wall Height, ft	Maximum Unbalanced Backfill Height[4], ft	Plain Concrete Minimum Nominal Wall Thk, Inches			Plain Masonry[2] Minimum Nominal Wall Thk, Inches		
		Soil Classes[3]					
		GW, GP, SW and SP	GM, GC, SM, SM-SC and ML	SC, MH, ML-CL and Inorganic CL	GW, GP, SW and SP	GM, GC, SM, SM-SC and ML	SC, MH, ML-CL and Inorganic CL
5	4	6	6	6	6 solid[5] or 8	6 solid[5] or 8	6 solid[5] or 8
	5	6	6	6	6 solid[5] or 8		
6	4	6	6	6	6 solid[5] or 8	6 solid[5] or 8	6 solid[5] or 8
	5	6	6	6	6 solid[5] or 8	8	10
	6	6	8	8	8	10	12
7	4	6	6	6	6 solid[5] or 8	8	8
	5	6	6	8	6 solid[5] or 8	10	10
	6	6	8	8	10	12	10 solid[5]
	7	8	8	10	12	10 solid[5]	12 solid[5]
8	4	6	6	6	6 solid[5] or 8	6 solid[5] or 8	8
	5	6	6	8	6 solid[5] or 8	10	12
	6	8	8	10	10	12	12 solid[5]
	7	8	10	10	12	12 solid[5]	Note 6
	8	10	10	12	10 solid[5]	12 solid[5]	Note 6
9	4	6	6	6	6 solid[5] or 8	6 solid[5] or 8	8
	5	6	8	8	8	10	12
	6	8	8	10	10	12	12 solid[5]
	7	8	10	10	12	12 solid[5]	Note 6
	8	10	10	12	12 solid[5]	Note 6	Note 6
	9	10	12	Note 7	Note 6	Note 6	Note 6

NOTES:

1. Use of this table for sizing concrete and masonry foundation walls in Seismic Zones 3 and 4 shall be limited to the following conditions:
   a. Walls shall not support more than 4 feet of unbalanced backfill.
   b. Walls shall not exceed 8 feet in height.
2. Mortar shall be Type M or S and masonry shall be laid in running bond. Ungrouted hollow masonry units are permitted except where otherwise indicated.
3. Soil classes are in accordance with Unified Soil Classification System (Figure 6-13).
4. Unbalanced backfill height is the difference in height of the exterior and interior finish ground levels. Where an interior concrete slab is provided, the unbalanced backfill height shall be measured from the exterior finish ground level to the top of the interior concrete slab.
5. Solid grouted hollow units or solid masonry units.
6. Wall construction shall be in accordance with Figure 6-15 or an engineered design shall be provided.
7. Engineered design is required.
8. Thickness may be 6 in., provided minimum specified compressive strength of concrete is 4,000 psi.

FIGURE 6-14

Minimum code requirements for unreinforced concrete and masonry foundation walls. ***(from Council of American Building Officials*** **One and Two-Family Dwelling Code,*, Falls Church, VA)*.**

REINFORCED CONCRETE AND MASONRY FOUNDATION WALLS[1]

Max. Wall Height, ft	Maximum Unbalanced Backfill Height[5], ft	Maximum Vertical Reinforcement Size and Spacing[2,3] for 8-inch Nominal Wall Thickness — Soil Classes[4]: GW, GP, SW and SP	GM, GC, SM, SM-SC and ML	SC, MH, ML-CL and Inorganic CL
6	5	#4 @ 48″ o.c.	#4 @ 48″ o.c.	#4 @ 48″ o.c.
	6	#4 @ 48″ o.c.	#4 @ 40″ o.c.	#5 @ 48″ o.c.
7	4	#4 @ 48″ o.c.	#4 @ 48″ o.c.	#4 @ 48″ o.c.
	5	#4 @ 48″ o.c.	#4 @ 48″ o.c.	#4 @ 40″ o.c.
	6	#4 @ 48″ o.c.	#5 @ 48″ o.c.	#5 @ 40″ o.c.
	7	#4 @ 40″ o.c.	#5 @ 40″ o.c.	#6 @ 48″ o.c.
8	5	#4 @ 48″ o.c.	#4 @ 48″ o.c.	#4 @ 48″ o.c.
	6	#4 @ 48″ o.c.	#5 @ 48″ o.c.	#5 @ 40″ o.c.
	7	#5 @ 48″ o.c.	#6 @ 48″ o.c.	#6 @ 40″ o.c.
	8	#4 @ 40″ o.c.	#6 @ 40″ o.c.	#6 @ 24″ o.c.
9	5	#4 @ 48″ o.c.	#4 @ 48″ o.c.	#5 @ 48″ o.c.
	6	#4 @ 48″ o.c.	#5 @ 48″ o.c.	#6 @ 48″ o.c.
	7	#5 @ 48″ o.c.	#6 @ 48″ o.c.	#6 @ 32″ o.c.
	8	#5 @ 40″ o.c.	#6 @ 32″ o.c.	#6 @ 24″ o.c.
	9	#6 @ 40″ o.c.	#6 @ 24″ o.c.	#6 @ 16″ o.c.

NOTES:
1. Mortar shall be Type M or S and masonry shall be laid in running bond.
2. Alternative reinforcing bar sizes and spacings having an equivalent cross-sectional area of reinforcement per lineal foot of wall shall be permitted provided the spacing of the reinforcement does not exceed 72 in.
3. Vertical reinforcement shall be Grade 60 minimum. The distance from the face of the soil side of the wall to the center of the vertical reinforcement shall be at least 5 in.
4. Soil classes are in accordance with Unified Soil Classification System (Figure 6-13).
5. Unbalanced backfill height is the difference in height of the exterior and interior finish ground levels. Where an interior concrete slab is provided, the unbalanced backfill height shall be measured from the exterior finish ground level to the top of the interior concrete slab.

FIGURE 6-15

Minimum code requirements for reinforced concrete and masonry foundation walls. ***(from Council of American Building Officials,*** **One and Two-Family Dwelling Code*****, Falls Church, VA)*****.**

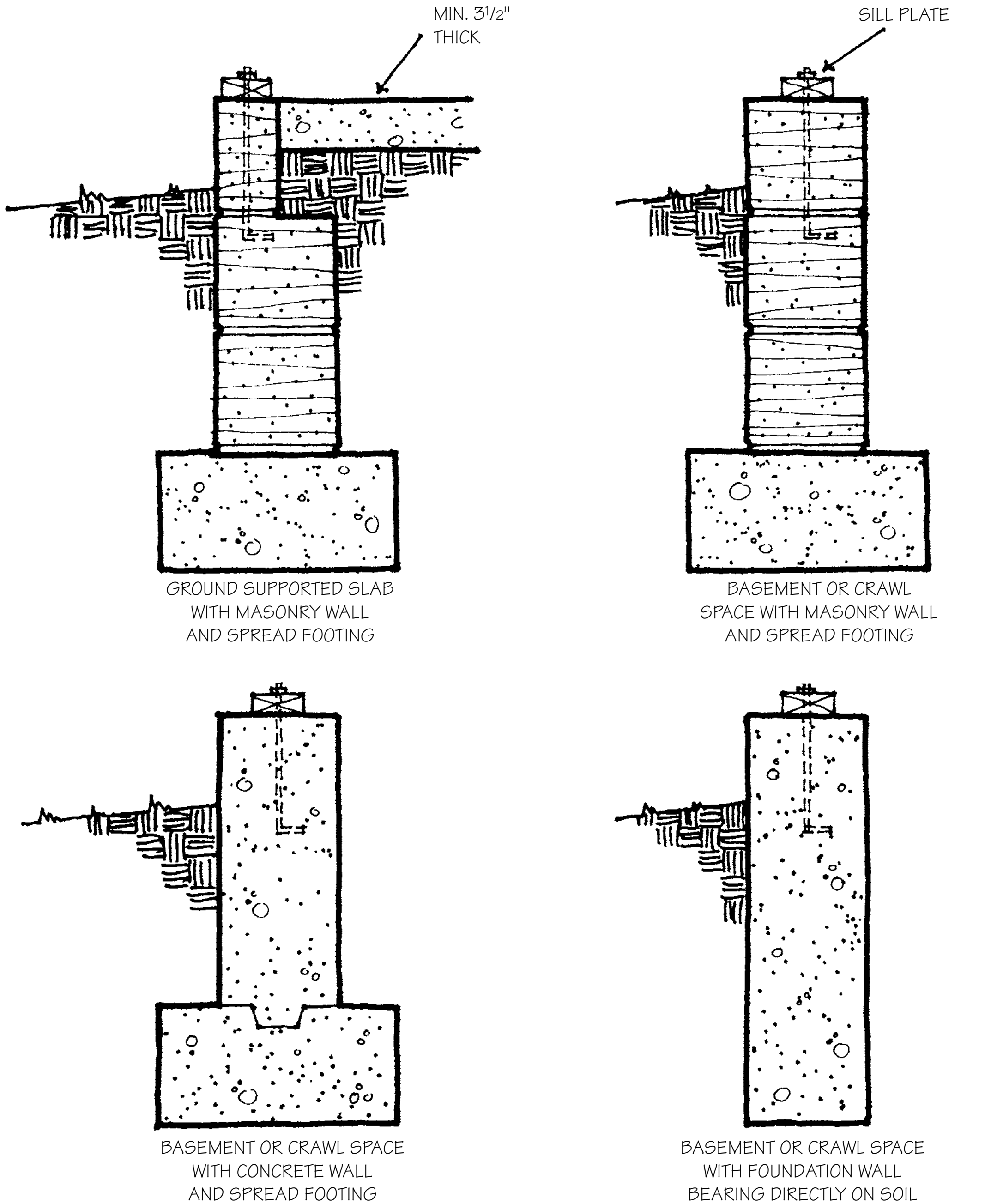


FIGURE 6-16

Types of foundation walls. ***(from Council of American Building Officials*** **One and Two-Family Dwelling Code,** ***Falls Church, VA)*.**

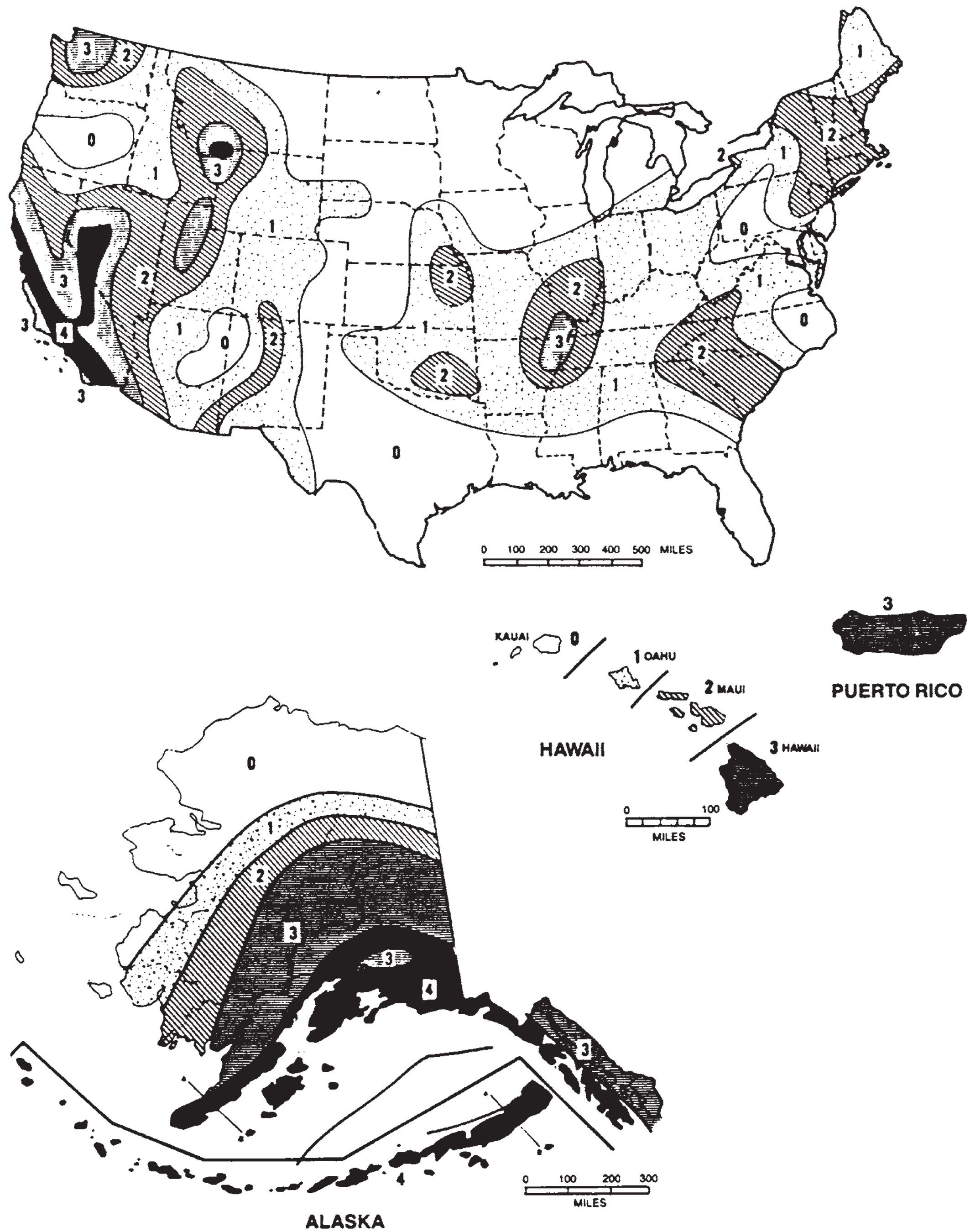


FIGURE 6-17

Seismic risk map. ***(from Council of American Building Officials*** **One and Two-Family Dwelling Code,** ***Falls Church, VA)*****.**

of the foundation wall (Figure 6-21). This will allow room for support of the veneer on the top of the foundation wall.

Figure 6-14 or 6-15 may be used to design concrete and masonry foundation walls except when any of the following conditions exist:

- The building official has determined that suitable backfill material is not available.
- Walls are subject to hydrostatic pressure from groundwater.

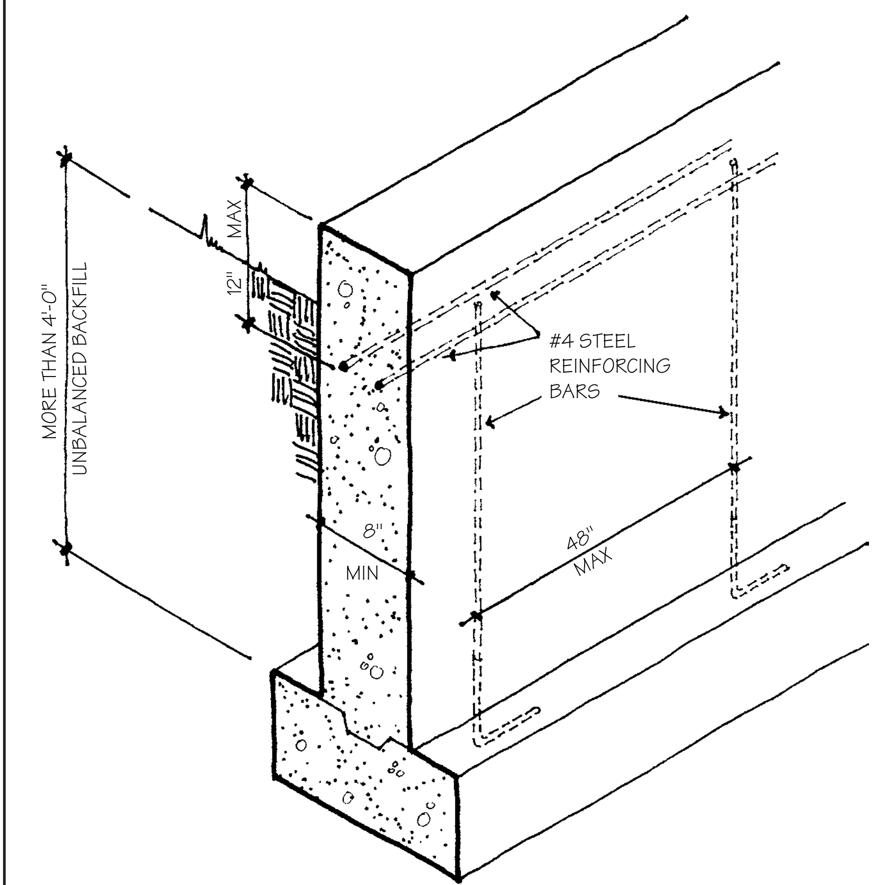


FIGURE 6-18

Minimum requirements for foundation walls in Seismic Zones 3 and 4 supporting more than 4 ft. of unbalanced backfill. ***(from Council of American Building Officials*** **One and Two-Family Dwelling Code,** ***Falls Church, VA)*****.**

FIGURE 6-19

Grouted and reinforced bond beam.

- Walls support more than 48 in. of unbalanced backfill and do not have permanent lateral support at the top and bottom.

When any of these conditions exist, walls must be designed in accordance with accepted engineering practice and in accordance with the requirements of an approved standard such as ACI 530/ASCE 5/TMS 402 *Building Code Requirements for Masonry Structures,* or ACI 318 *Building Code Requirements for Reinforced Concrete.*

6.3.2 Basement Walls

Basement walls are essentially just tall foundation walls which will enclose habitable space instead of a crawl space. Their construction is essentially the same, and the minimum requirements discussed above for foundation walls apply equally to basement walls. The taller the wall, though, the greater the lateral load it must resist as the backfill soil pushes against it. Lateral support at the top of the wall is provided by the first-floor framing, and at the bottom by the footing and basement floor slab. Since the first floor helps resist soil pressures, backfilling should be delayed until the floor construction is in place. If earlier backfill is unavoidable, temporary bracing must be provided to prevent possible collapse of the wall. Walls should be allowed to cure for at least three weeks so that sufficient strength is gained before any backfilling may begin. The gravel and soil backfill should be placed in depths of 12 to 24 in. at a time to avoid large impact loads against the wall.

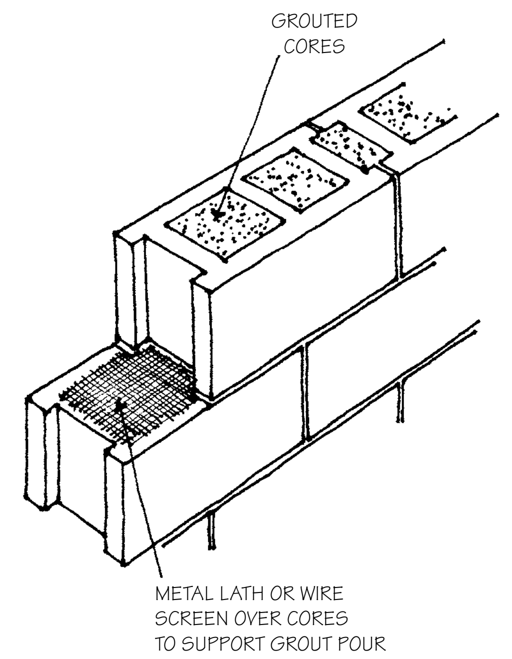


FIGURE 6-20

Grout screen.

6.3.3 Formwork

Forms for concrete walls may be built of lumber or of plywood, so long as they have sufficient strength to resist the pressure of the wet concrete. The taller the wall, the greater the force exerted by the wet concrete and the stronger the forms must be. For short walls, lumber forms are easy to assemble and are economical, especially if the form boards can be reused in framing the structure or for future formwork. For taller walls, 3/4-in. or 1-in. plywood braced with 2 × 4 frames are more economical. Lumber forms should be fitted tightly together so the concrete can't leak out, and braced with vertical 2 × 4 studs at 24 in. on center. Plywood forms should be braced with vertical 2 × 4 studs at 16 in. on center. For plywood forms, double 2 × 4 wales should be placed horizontally at 18 in. on center, beginning 12 in. from the bottom of the form (Figure 6-22 right). For lumber forms, double 2 × 4 wales should be spaced 24 in. on center, also beginning 12 in. from the bottom of the form (Figure 6-22 left). At the corners, alternating wales should run long so they can be nailed or srewed together for added strength (Figure 6-23).

Wall forms must incorporate ties or spreaders to keep the sides from bowing. One of the simplest methods uses wire snap ties which simultaneously hold the side walls of the forms together to prevent bulging and keep them spread apart at the right dimension. Snap ties should be located on 16-in. or 24-in. centers midway between each vertical stud and arranged in horizontal rows at the same height as the wales. The forms are drilled with 5/8-in. diameter holes at the proper

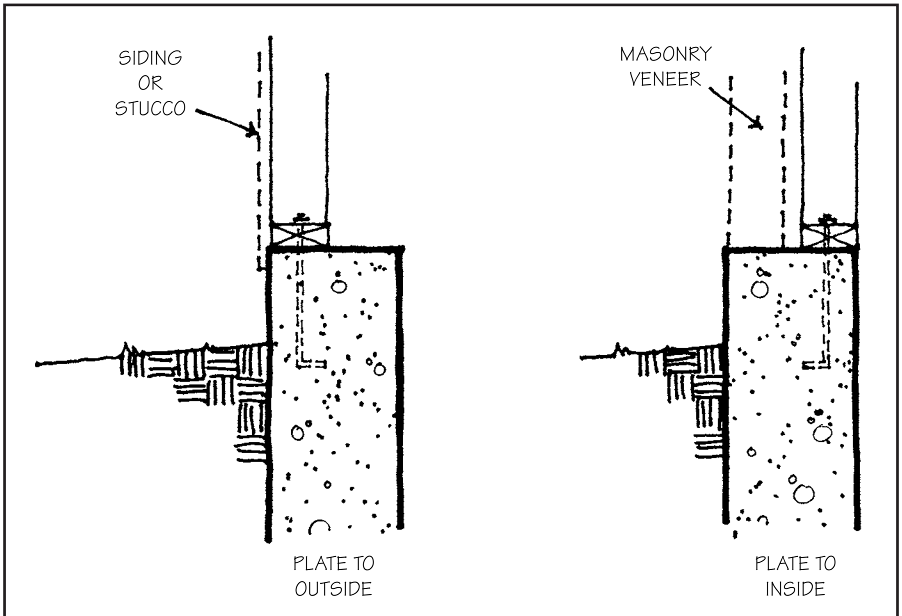


FIGURE 6-21

Attaching plates to foundation wall.

locations and the ties installed after one side of the form is in place. The second side of the form is then erected, fitting the form boards or plywood over the ties. Once the second set of wales is in place, metal wedges are used to secure the ties snugly (Figure 6-24). Snap ties can also support horizontal reinforcing bars in concrete walls, using wire to tie the bars in place. Forms can be stripped after two or three days the protruding wire of the snap ties broken off and the plastic cones pried out. If the wall will be exposed to view, the holes left by the cones can be patched with cement paste.

6.3.4 Reinforcement

Reinforcing steel is used in concrete and masonry walls to increase stiffness and resistance to lateral loads. The Code permits unreinforced walls where lateral loads are moderate, increasing the wall thickness requirements as the height of the wall and the lateral loads increase. The Code also prescribes minimum vertical reinforcement size and spacing for walls with greater height or unbalanced backfill than is permitted for unreinforced walls. Vertical steel reinforcing bars

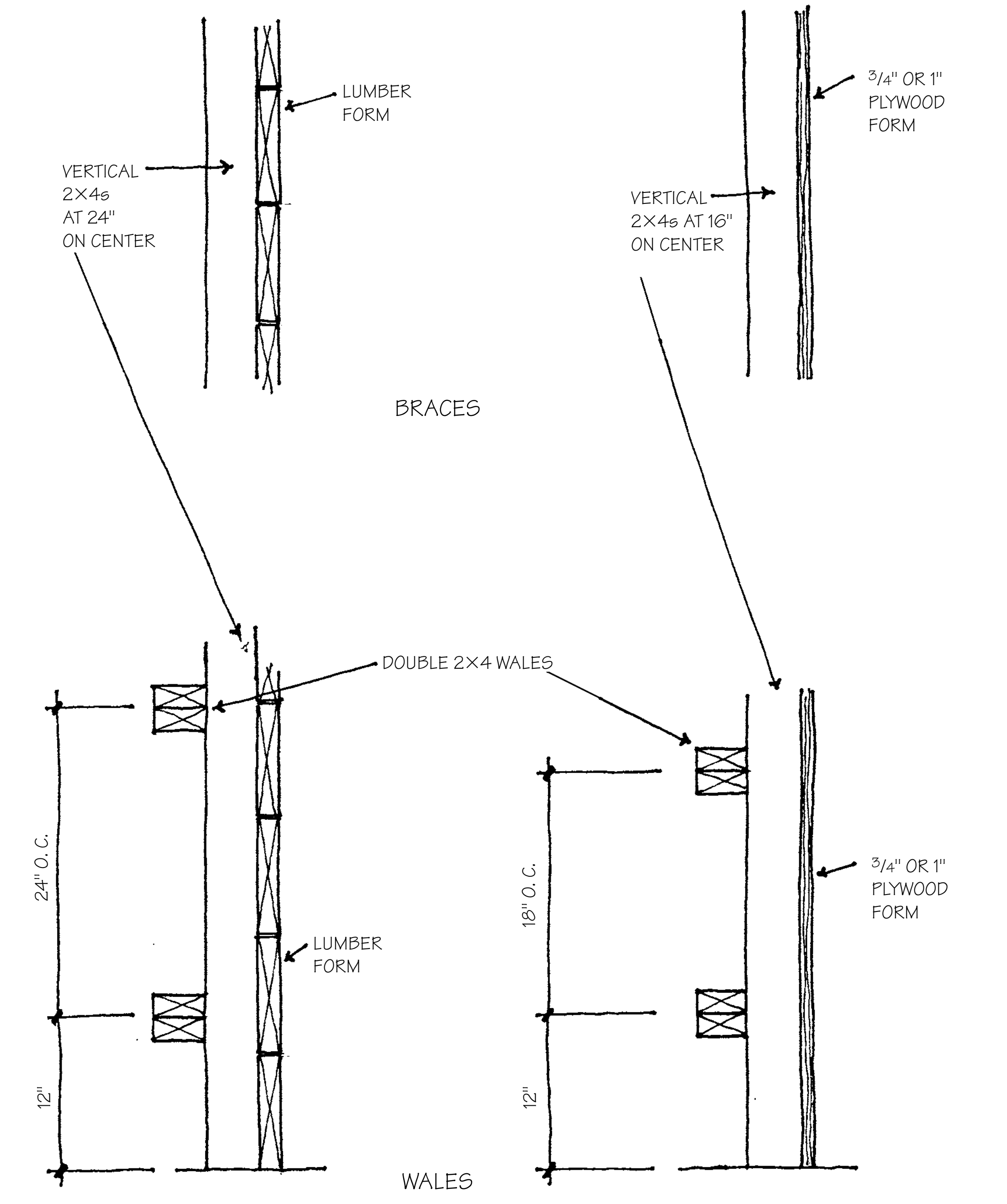


FIGURE 6-22

Bracing tall concrete forms.

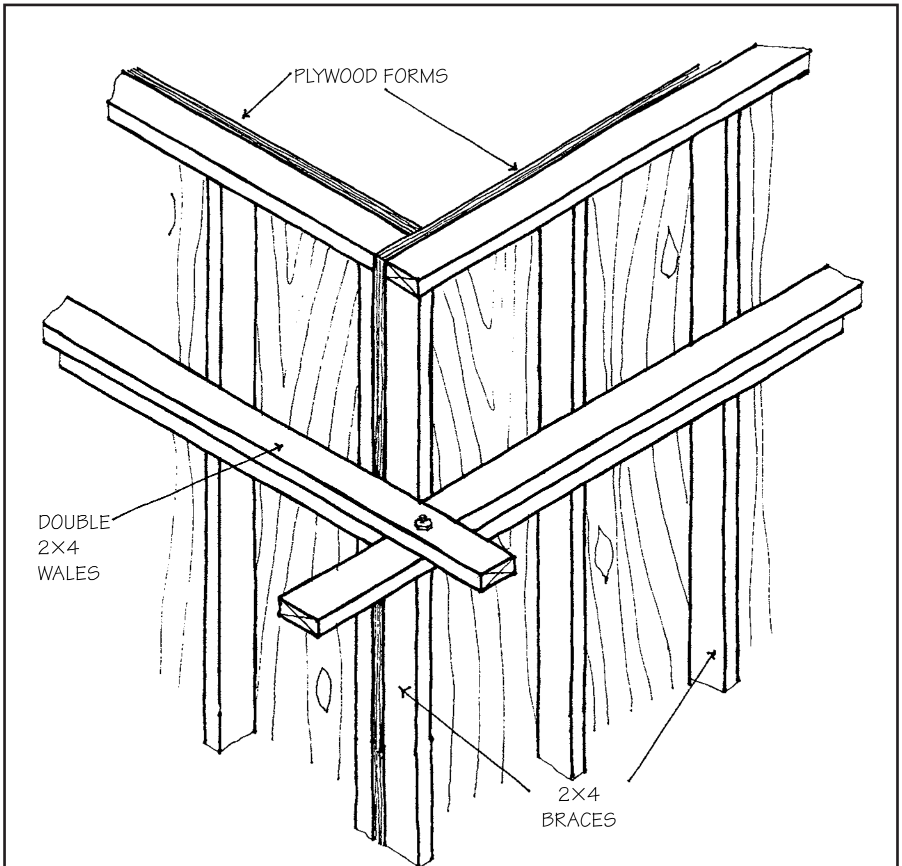


FIGURE 6-23

Corner wales for tall concrete forms.

in the wall must always be tied to the footing (Figure 6-25). Vertical stiffness in unreinforced masonry walls can also be increased by adding thickened sections called *pilasters* (see Figure 6-26). Pilasters are formed by turning concrete blocks perpendicular to the wall and bonding the projecting units into the wall, overlapping them with the adjacent blocks in alternating courses. Where pilasters project from one or both faces of a wall, the footing should be wider as well to accommodate the extra wall thickness.

Reinforcing steel in concrete and masonry walls not only increases strength, but it also helps control shrinkage cracking by distributing shrinkage stresses more evenly throughout the wall. Prefabricated joint reinforcement also controls shrinkage cracking in concrete masonry walls and can be used when codes do not require the wall to be structurally reinforced. Controlling shrinkage cracking in basement walls is important in maintaining the integrity of waterproofing materials applied to the wall and preventing water penetration through the cracks.

6.3.5 Basement Slabs

Basement floor slabs are usually supported on a gravel drainage bed with the edges resting on the perimeter footing (Figure 6-27). The CABO *One and Two Family Dwelling Code* requires only that the minimum slab thickness be 3-1/2 in. and the concrete strength a minimum of 2,500 psi. The Code does not include any requirements for reinforc-

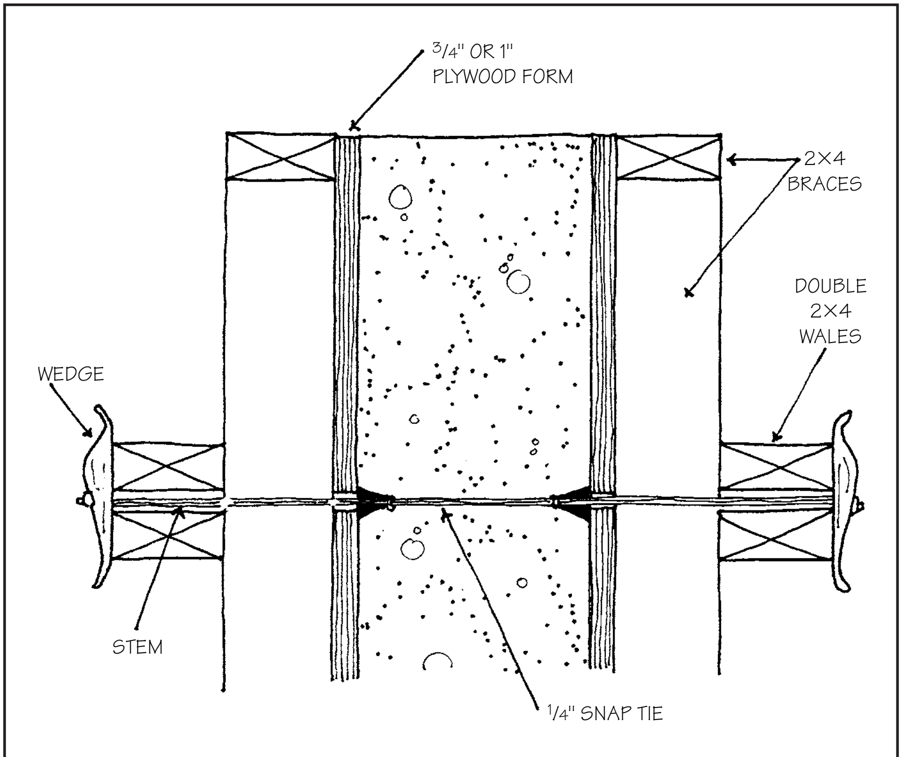


FIGURE 6-24

Snap ties for concrete forms. ***(from Portland Cement Association,*** **The Homeowner's Guide to Building with Concrete, Brick and Stone,** ***PCA, Skokie, Illinois)*****.**

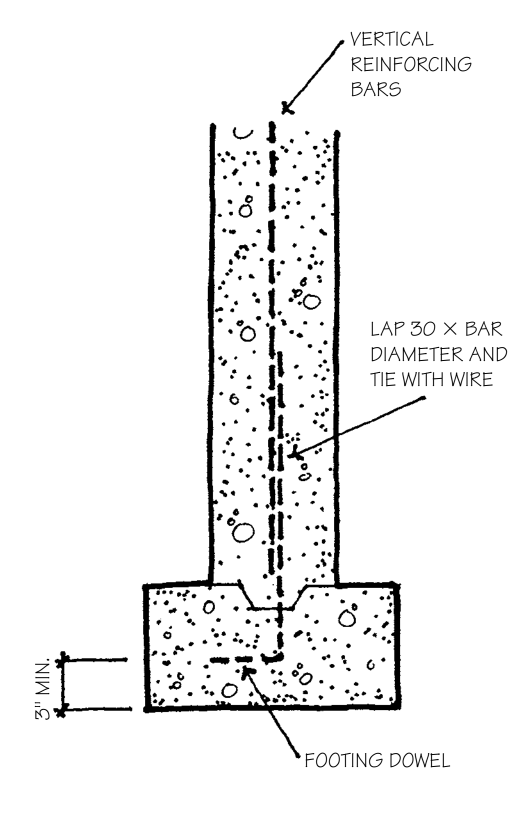


FIGURE 6-25

Footing-to-foundation wall connections.

ing steel in slabs, but reinforcing may be required by some engineered designs. In thin slabs, steel cannot be set the recommended 3 in. above the subgrade, so it should be placed at the midpoint of the slab thickness. If the basement is properly designed for good drainage of soil moisture, the reinforcing should be protected well enough to prevent corrosion. Drainage and waterproofing, insulation, and vapor retarders are discussed later in this chapter.

6.4 Slabs-on-Grade

In warm climates where the frost depth is minimal, shallow concrete foundations are often designed and poured monolithically with the floor slab. These are referred to as *slabs-on-grade* or *slabs-on-ground.* The Code still requires that the bottom of the footing be set a minimum of 12 in. below the adjacent grade, that its minimum width is appropriate to the type of soil (refer to the table in Figure 6-4), that the slab be at least 3-1/2 in. thick, and the concrete at least 2,500 psi. Interior bearing walls require an integral footing with the same required width at the bottom as the perimeter footing, but usually with a reduced depth (Figure 6-28). For masonry veneers, a perimeter ledge allows the masonry to sit below the level of the finish floor (Figure 6-29). All top soil and vegetation must be removed from the area within the footings and replaced with a compacted fill material that is free of vegetation and foreign material.

There are no requirements for steel reinforcing, but sill plates must be anchored to the foundation with 1/2-in-diameter bolts spaced 6 ft. on center and not more than 12 in. from corners. The bolts must extend at least 7 in. into the concrete and have a 90° bend at the bottom. The top of the slab must be at least 4 in. above the adjacent finished grade where masonry veneer is used and at least 6 in. above grade elsewhere. The ground must slope away from the slab a minimum of 6 in. within the first 10 ft. If lot lines, adjacent walls, natural slopes, or other physical barriers prohibit the mini-

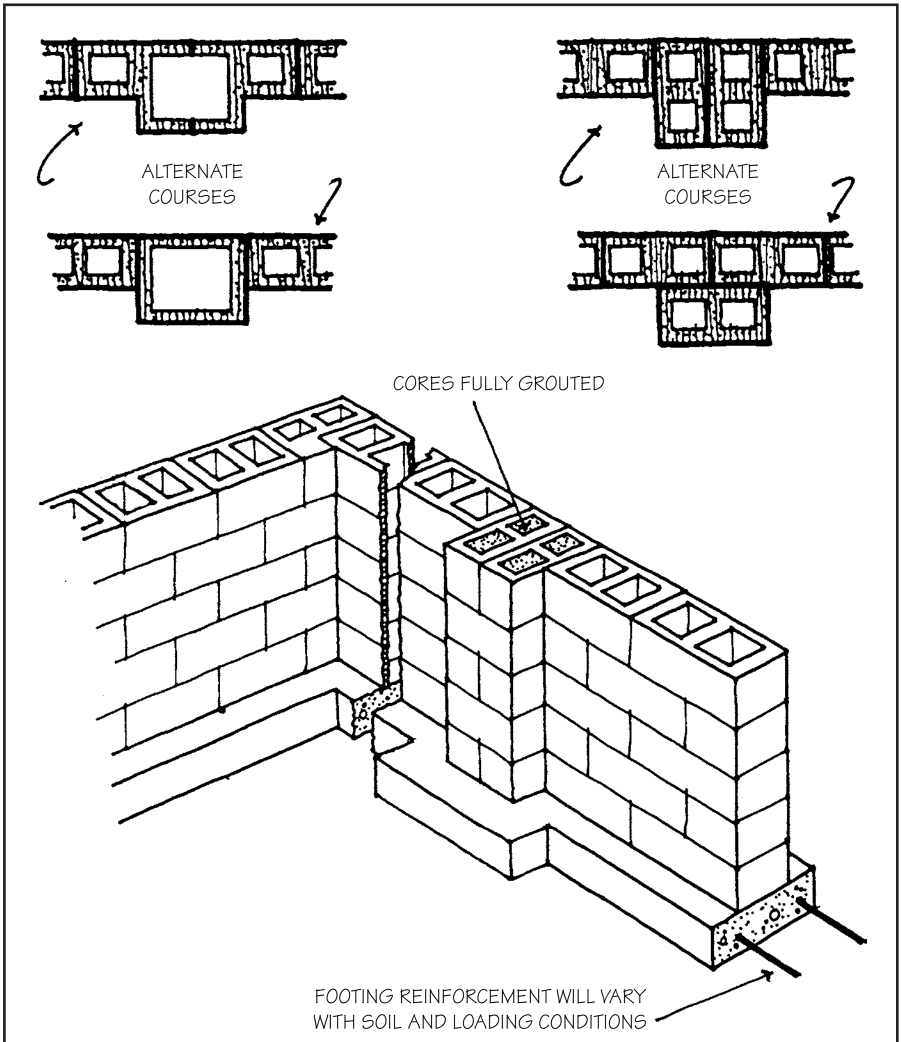


FIGURE 6-26

Basement or foundation wall with pilasters. ***(from NCMA,*** **TEK 1,** ***National Concrete Masonry Association, Herndon, VA).***

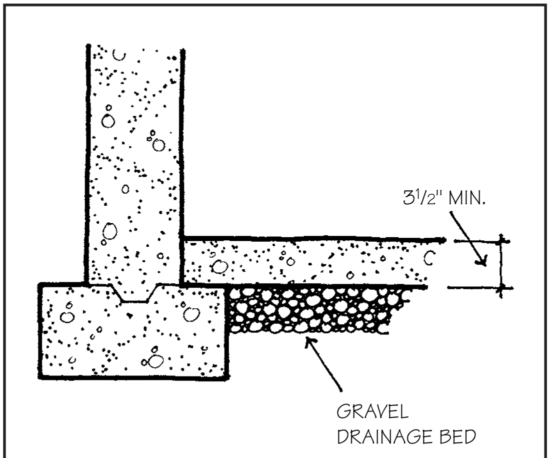


FIGURE 6-27

Basement slabs.

mum slope, area drains or earth swales must be provided to ensure drainage away from the structure. Like basement floor slabs, slabs-on-grade are often supported on gravel drainage beds. Because the footings are shallow and the slabs set above grade, soil moisture is usually not a problem except on poorly drained sites or where the water table is very close to the ground surface, but water vapor diffusion from the soil must be considered, and perimeter insulation may be necessary in colder climates. Soil moisture, insulation, and vapor retarders are discussed below.

6.5 Drainage and Waterproofing

Water moves through the soil by gravity flow and capillary action and exerts hydrostatic pressure against basement walls and slabs which

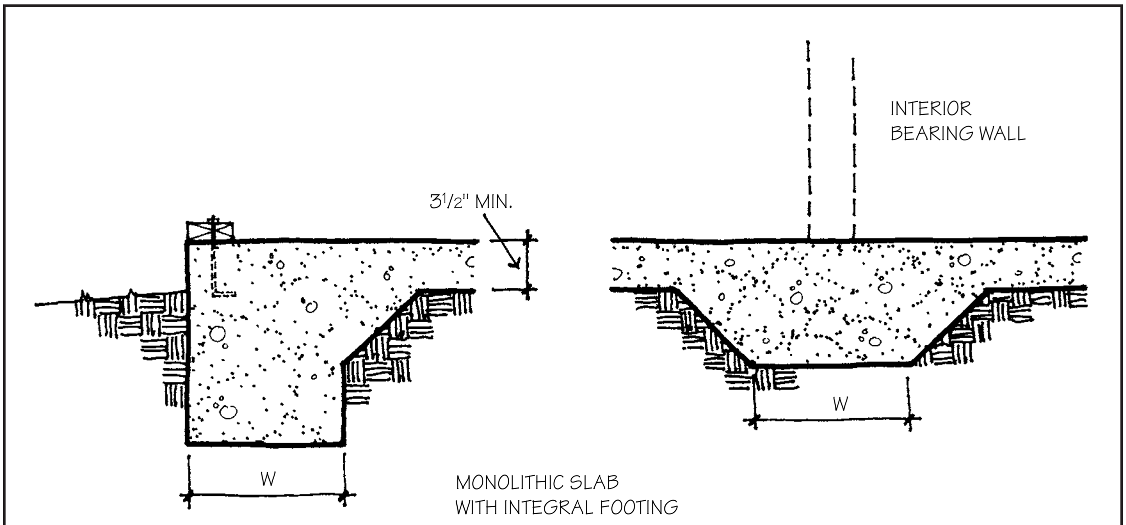


FIGURE 6-28

Slabs on grade. ***(from Council of American Building Officials*** **One and Two-Family Dwelling Code,*, Falls Church, VA)*.**

are at or below the level of the groundwater. Water vapor diffuses through soil because of vapor pressure differentials between areas of higher and lower temperatures. To prevent moisture problems, both water and water vapor movement must be considered in the design of basements and slabs-on-grade.

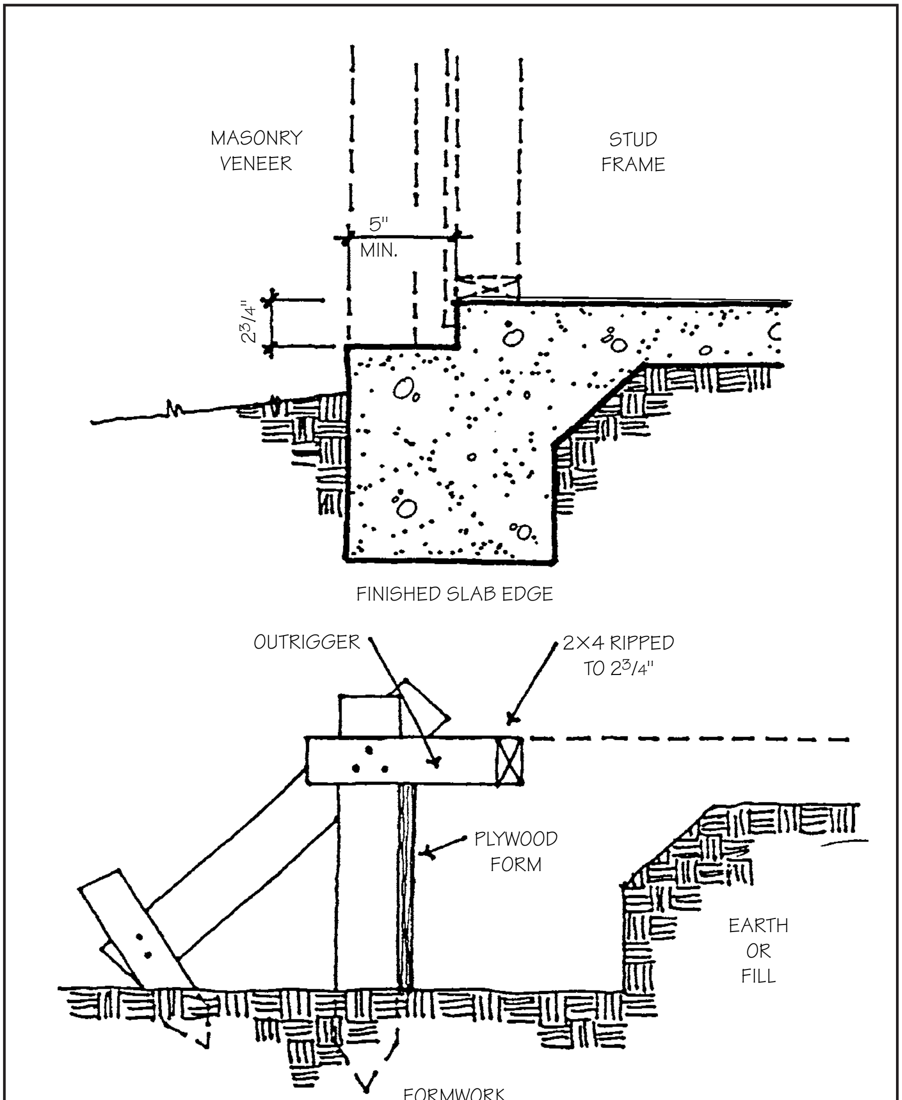


FIGURE 6-29

Recessed masonry ledge.

6.5.1 Water Movement in Soils

At some elevation below every building site, there is water in the ground because of rain seeping into the soil and because of the natural water content of the earth. This groundwater may be close to the surface or far below grade. The top elevation of groundwater is called the groundwater level or *water table.* Water table varies with climate, amount of rainfall, season, and, to some extent, with type of soil. The water table follows the general contours of the land but is closer to the surface in valleys and farther from the surface on hills and ridges. Water moves laterally through the soil by gravity flow to lower elevations. The direction of groundwater flow is always in the direction of lower elevations until the water emerges in a spring, stream, or other open body of water (Figure 6-30).

A soil boring test can identify the soil types which will be encountered below a building site, as well as the elevation of the water table. Since the water table can vary with climate and amount of rainfall, it is important to understand that the water table listed in a geotechnical report should not be taken as an absolute. If soil tests are performed during the rainy season, the elevation of the water table may be at its highest expected level, but if the tests are done during a period of drought, the water table may be unusually low and not representative of the normal conditions which would be encountered. If data from a

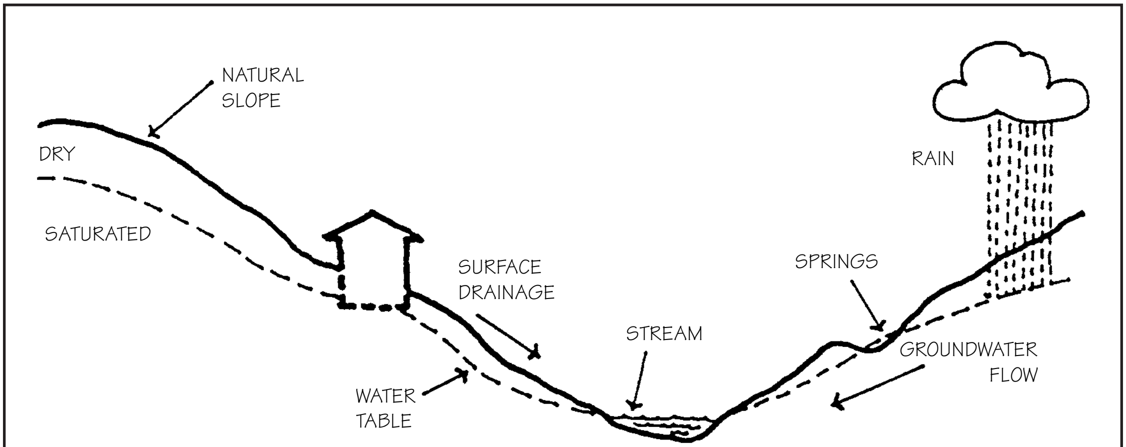


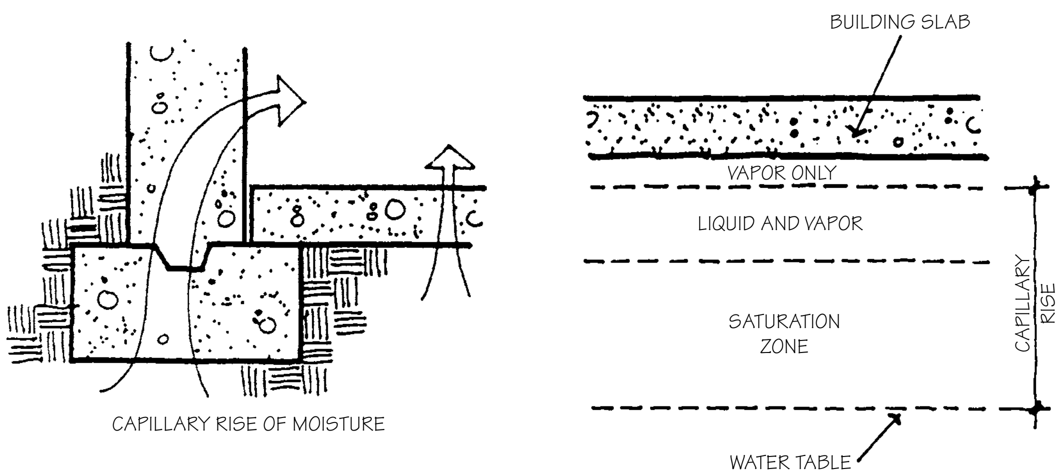
FIGURE 6-30

Groundwater. ***(from Callendar, John H.,*** **Timesaver Standards for Architectural Design Data,** ***McGraw-Hill, New York)*****.**

soil test is not available, excavations at the site can provide some contemporaneous information. Water which seeps into an excavation will rise to the level of the current water table. If the excavations are made during the dry season, the water table is probably lower than normal. If the excavations are made during the rainy season, the water table may be at its highest. Planning for drainage and waterproofing a basement space should be based on worst-case scenario because it is very difficult and very expensive to correct below-grade moisture problems after the backfill is in place. The cost of adding an extra measure of protection up front is minimal and can reduce or eliminate the callbacks required to deal with leaky or damp basements.

Hydrostatic pressure is the pressure exerted by the weight of a fluid such as water. The hydrostatic pressure exerted by groundwater at any point against a basement wall is equal to the depth of that point below the water table times the unit weight of water (which is 62.4 pcf). If the bottom of the wall is 8 ft. below the water table, the hydrostatic pressure at that point is $8 \times 62.4 = 499.2$ lbs. per square foot of wall area. The lateral pressure of the soil itself is slightly reduced because of the buoyancy of the water it contains, but the added hydrostatic pressure significantly increases the structural load on the wall. The hydrostatic uplift pressure on the bottom of a basement slab is calculated in the same way. Both structures and waterproofing membranes must be able to withstand the lateral and uplift loads created by hydrostatic pressure. As an alternative to resisting the full force of the hydrostatic load, groundwater can be diverted away from a basement by installing subsurface drains to lower the water table. Draining water away from a building reduces structural loads on walls, footings, and slabs as well as hydrostatic pressure on waterproofing membranes.

In addition to lateral gravity flow, water can move upward through soil from the water table by *capillary action.* The rate at which this capillary rise occurs depends on particle size and distribution and the resulting size of voids or pores between soil particles. Clay soils have the finest pore structure and can draw capillary moisture upward from a water table many feet below. Coarse, sandy soils generally have a pore structure so large that capillary rise is minimal. The capillary moisture content of soil varies in direct proportion to the fineness of the soil. Capillary moisture cannot be drained out of soil because the surface tension within the pore structure of the soil holds the water tightly. Soil particles less than 1/480 in. are called *fines.* Laboratory tests of soils containing 56% fines showed moisture constantly rising to the surface and evaporating at an average rate of about 12 gallons per 1000 sq. ft. per 24 hours with a water table as much as 30 in. below the surface. Field tests have also shown that substantial amounts of moisture migrate upward through fine soil even when the water table is as much as 20 ft. below the surface. Figure 6-31 indicates the height of capillary moisture rise which can be expected with various soil types. Any basement or slab-on-grade built without protection on moist soil would be exposed to a continuous capillary migration of moisture toward the structure. Since both concrete and



Soil Type	Saturation Zone, ft	Capillary Rise, ft
Clay	5+	8+
Silt	5+	8+
Fine Sand	1-5	3-8
Coarse Sand	0-1	1-3
Gravel	0	0

FIGURE 6-31

Capillary moisture rise. ***(from Harold B. Olin,*** **Construction Principles, Materials and Methods,** ***Van Nostrand Reinhold).***

masonry are absorptive materials with a fine pore structure, the water rising through the soil by capillary action would be picked up by the concrete or masonry and continue its capillary migration.

To prevent the capillary rise of water into a slab-on-grade or below-grade slab, an intervening layer of material must be added which is either impervious to moisture penetration or has a pore structure large enough to prevent capillary suction. Gravel and crushed rock are the materials most commonly used to provide a capillary break under a slab-on-grade or below-grade slab. The aggregate should be mostly single graded and of 3/4 in. maximum size. Capillary water penetration can also be prevented by installing dampproofing or membrane waterproofing as a barrier against capillary movement (Figure 6-32).

6.5.2 Water Vapor Movement in Soils

Below-grade vapor pressures within the soil, particularly if capillary moisture is present, are usually higher than vapor pressures within buildings. This pressure differential creates a flow of vapor from the soil toward the structure, regardless of season or interior heating or cooling cycles (Figure 6-33). Vapor can then migrate through a con-

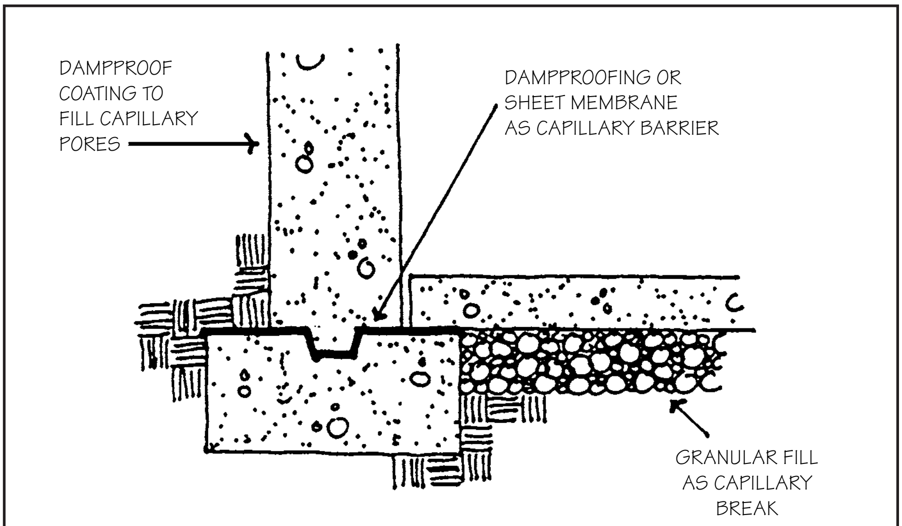


FIGURE 6-32

Capillary barrier. ***(from Beall, Christine,*** **Thermal and Moisture Protection Manual, McGraw-Hill, New York).**

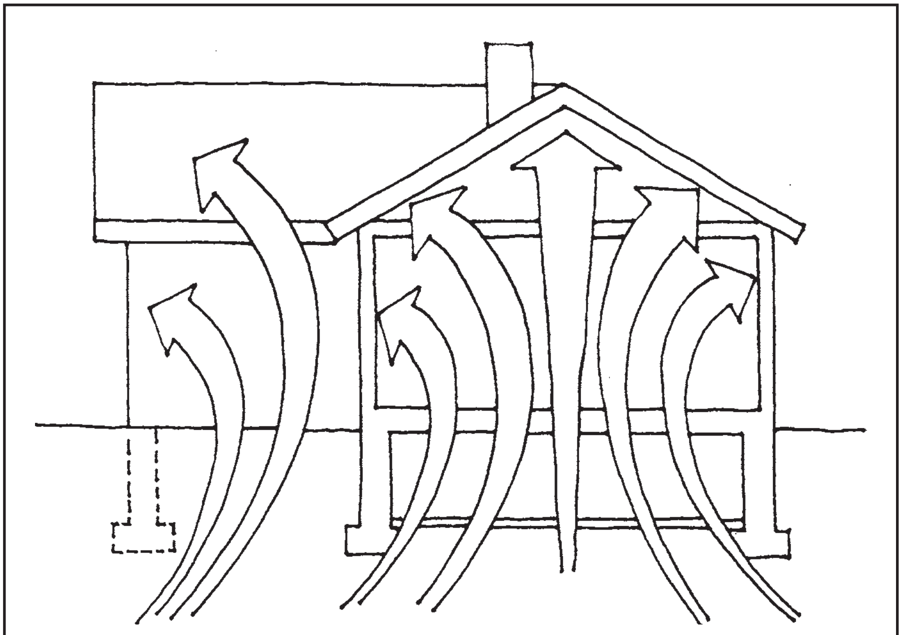


FIGURE 6-33

Vapor flow from soil. ***(from W. R. Meadows, Inc.*** **The Hydrologic Cycle and Moisture Migration*).***

crete slab or framed floor structure into the building. Vapor migration from the soil, if unimpeded, can provide a continuous supply of below-grade moisture flowing into the structure and then migrating outward through the walls and roof. If cooled below its dewpoint, this continuous supply of moist air will condense to liquid on interior surfaces, or condense as liquid or frost within the walls or roof of the building envelope. Vapor flow into buildings from the soil is a primary cause of the damp feeling often associated with basements.

6.5.3 Surface and Subsurface Drainage

Surface drainage should be the first line of defense in every residential moisture protection system. Groundwater can be controlled to a great extent by reducing the rate at which rainwater and surface runoff enter the soil adjacent to a building. Roofs typically concentrate collected rain water at a building's perimeter where it can cause serious groundwater problems (Figure 6-34 top). Water that is drained quickly away from a building at the ground surface cannot enter the soil and contribute to below-grade moisture problems. Roof overhangs, gutters, and downspouts provide effective control for sloped roofs by diverting the runoff away from the building (Figure 6-34 bottom). Site selection, building orientation, and grading should provide slopes away from the building, and ground swales and troughs can also be used to redirect surface runoff.

Backfill adjacent to a building should be compacted sufficiently to prevent settlement and the possibility of ponding water, which might drain toward the foundation wall. Backfill materials that contain a high percentage of fines may absorb and hold surface water and rain water, concentrating the moisture immediately adjacent to the building. A low-permeance cap of compacted clay soil can be installed under grassy areas. Planting beds located next to the building walls should always be well drained to avoid concentrating moisture along the foundation line. Sidewalks located adjacent to a building can prevent groundwater absorption but may cause backsplash and soiling on the walls. Sidewalks should always be sloped away from the building a minimum of 1/2 in. per foot. The joint between the sidewalk and the building should be sealed with a traffic-grade silicone or urethane sealant if substantial rainfall, accumulated snow drifts, or exposure to roof or site runoff is expected.

Subsurface drainage systems can collect and divert groundwater away from the walls and floor of a basement and relieve hydrostatic pressure. The most common method of keeping groundwater away from basement structures is to provide a *perimeter drain* or *footing drain* in the form of perforated, porous, or open-jointed pipe at the level of the footings. Perforated drains are generally preferable to the porous pipe and open-jointed systems. When perforated drains are used, they should be installed with the perforations on the bottom so that water rises into the pipe. Perimeter drains artificially lower the water table below the elevation of the floor and eliminate hydrostatic pressure against the walls and the bottom of the slab (Figure 6-35).

Perimeter drains must be placed below the floor level but above the bottom of the footing. As a rule of thumb, the bottom of the footing should be at least 4 in. below the bottom of the drain to prevent undermining the footing stability. Crushed stone or gravel should always be placed above and below perimeter drains to facilitate water flow. The

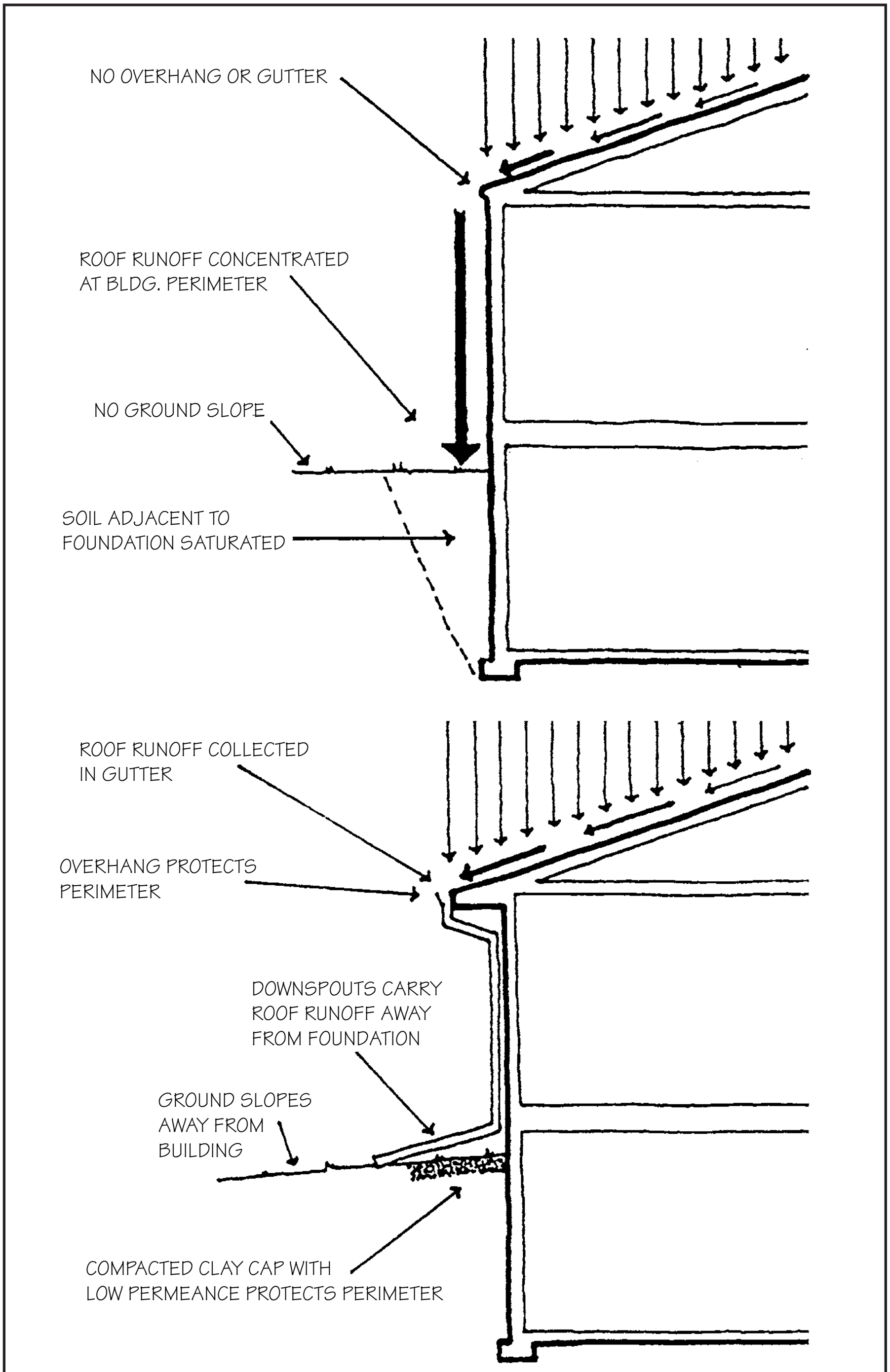


FIGURE 6-34

Roof runoff. ***(from Joseph Lstiburek and John Carmody,*** **Moisture Control Handbook,** ***Van Nostrand Reinhold).***

gravel bed must be protected from soil clogging with a filtering cover made from landscape fabric. This will allow water to flow toward the drain but keep soil from clogging the voids between gravel particles. For clay soils, which have poor drainage and only limited amounts of groundwater flow, a 4-in. drain is usually adequate. For sandy soils with better drainage and more groundwater flow, a 6-in. drain is needed. For gravely soils with good drainage and large ground water flow, a drain as large as 8 in. may be necessary.

Subsurface drainage can also be used to relieve hydrostatic pressure against the full height of a basement wall. A free-draining gravel backfill that extends the height of the wall allows groundwater to flow by gravity down to the level of the drain (Figure 6-36 top). The gravel should be carried up the wall to within a few inches of the ground surface with only a covering of topsoil for landscaping purposes. Proprietary insulation board with vertical drainage channels can be used instead of the gravel backfill (Figure 6-36 bottom). These drainage mats are generally easy to install and help to insulate the basement as well. The insulation is a polystyrene board which is impervious to moisture damage.

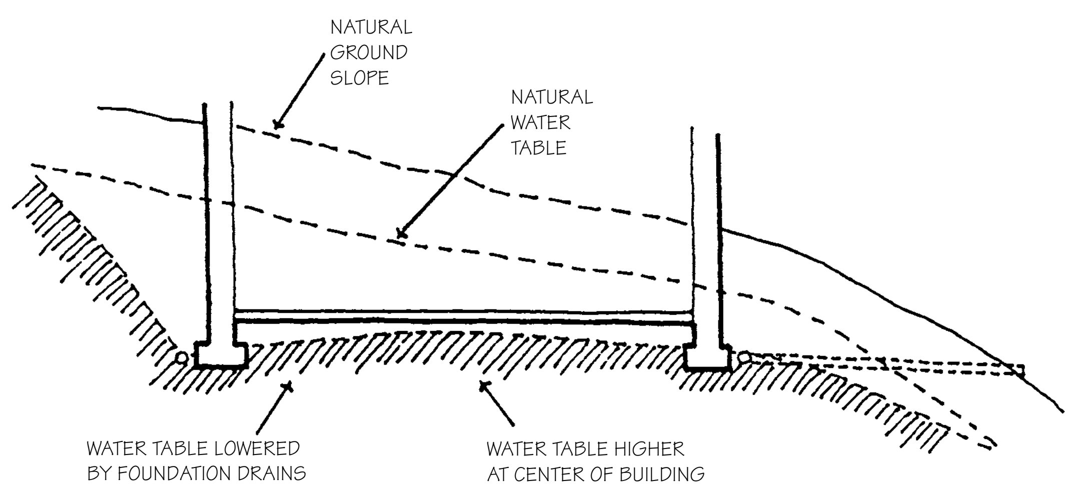


FIGURE 6-35

Drains lower water table. ***(from Callendar, John H.,*** **Timesaver Standards for Architectural Design Data,** ***McGraw-Hill, New York).***

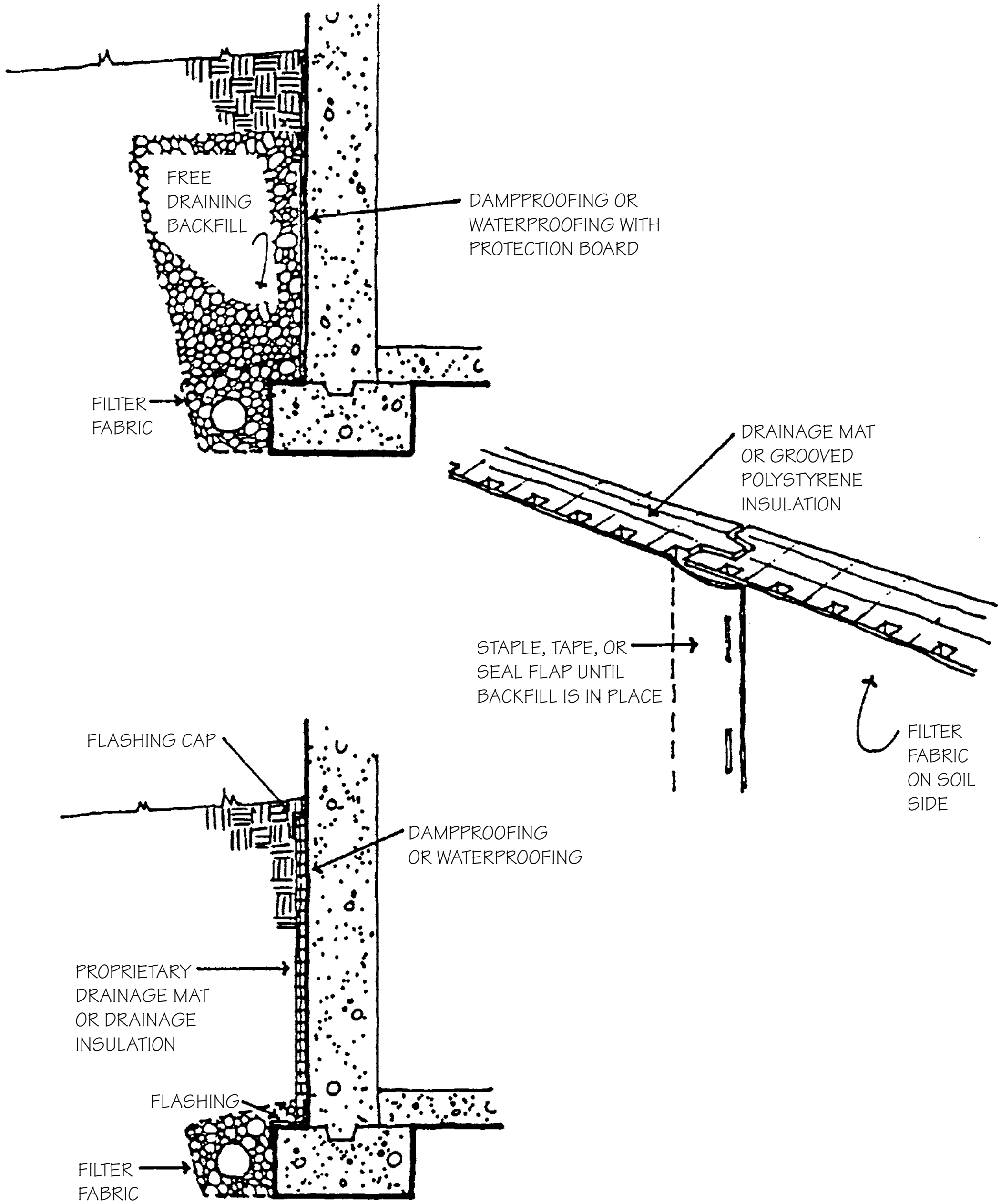


FIGURE 6-36

Drainage backfill. ***(from Beall, Christine,*** **Thermal and Moisture Protection Manual, McGraw-Hill, New York).**

Water collected by perimeter drains should be drained by gravity outflow to an exposed lower elevation, to a dry well that is above the water table, or to an approved storm sewer system. When these disposal methods are not feasible or practical, it will be necessary to collect the water in a sump and pump it out mechanically. Perimeter drains are often located just inside rather than outside the footings, particularly when a sump is necessary. Weeps should be located every 32 in. along the base of the foundation wall or at the top of the footing to allow any water which builds up on the outside of the wall to flow into the gravel bed inside the footing and then into the drain (Figure 6-37). Floor slabs should be cast at a level above the weep holes.

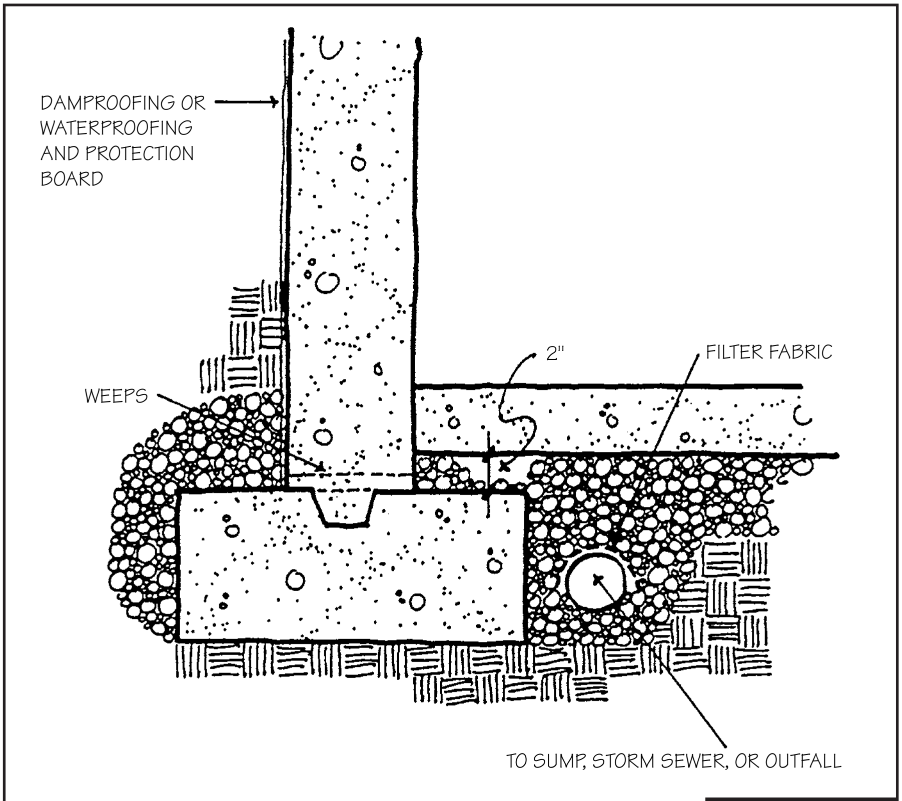


FIGURE 6-37

Interior drain for sump. ***(from Beall, Christine,*** **Thermal and Moisture Protection Manual, McGraw-Hill, New York).**

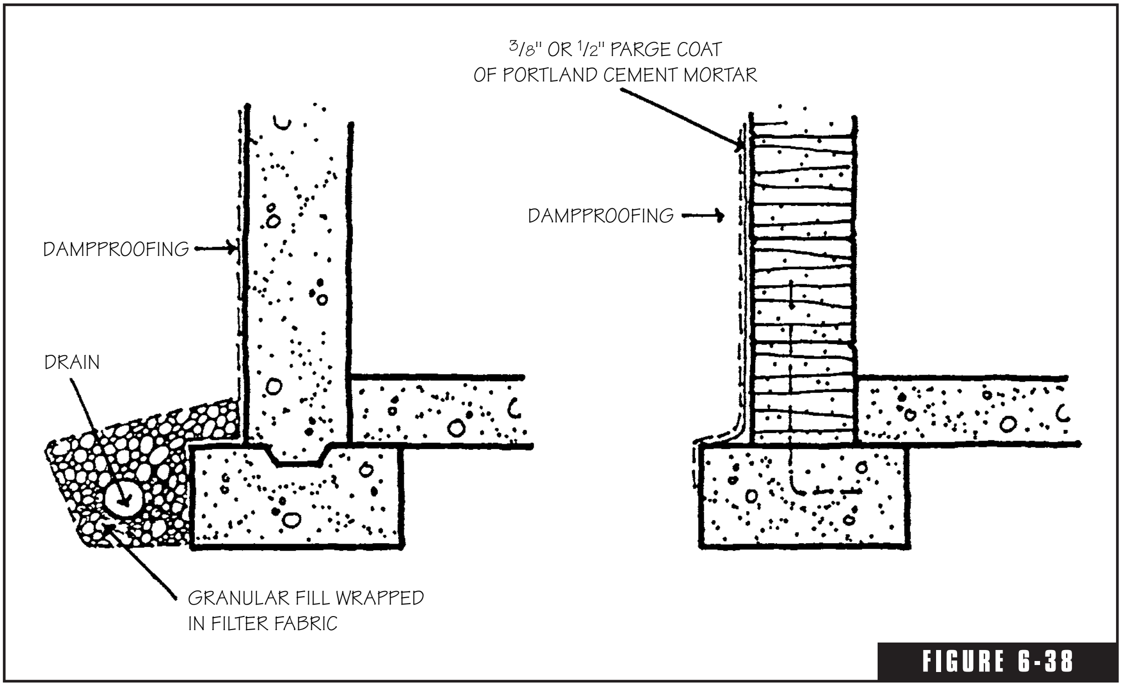
6.5.4 Waterproofing Membranes and Dampproof Coatings

The difference between waterproofing and dampproofing is one of degree. *Waterproofing* is the treatment of a surface or structure to prevent the passage of liquid water under hydrostatic pressure. *Dampproofing* is the treatment of a surface or structure to resist the passage of water in the absence of hydrostatic pressure. Where waterproofing is defined in absolute terms as *preventing* water infiltration even under extreme conditions, dampproofing is defined in relative terms as *resisting*—but not necessarily preventing—water infiltration under moderate conditions.

Some building codes dictate the use of either dampproofing or waterproofing on below-grade structures. Where no specific code mandates exist, the decision to provide footing drains, a drainage type backfill or drainage mat, dampproofing, or waterproofing should be based on the amount of moisture in the soil and the level of the water table. If the water table may fluctuate under different seasonal or weather conditions, protection should include a waterproof membrane in addition to subsurface drainage. If steel reinforcing is used in concrete or masonry basement walls (including joint reinforcement in concrete masonry), sufficient protection must be provided to prevent moisture absorption into the wall and corrosion of the metal.

In dry and moderate climates with deep water tables, or on well-drained sites with no history of groundwater problems and no possibility of a rising water table, a dampproof coating will inhibit the absorption of any groundwater which reaches the wall surface. Subsurface drainage can enhance the performance of the dampproofing by minimizing the amount of water which reaches the wall. Dampproof coatings provide resistance to moisture penetration by closing the capillary pores in concrete and masonry substrates. Dampproofing will not resist moisture penetration under hydrostatic pressure, and the cementitious and mastic materials typically used for these coatings do not have the ability to bridge across cracks. For dry or well-drained soils with low water tables, Figure 6-38 illustrates appropriate drainage and dampproofing measures.

Parging consists of a 3/8-in. to 1/2-in. thick coating of a portland cement and sand mortar mix applied in two layers of approximately equal thickness. The mix should be proportioned 1 part cement to 2-1/2 parts sand by volume. The wall surface should be dampened before



Dampproofing. ***(from Beall, Christine,*** **Thermal and Moisture Protection Manual, McGraw-Hill, New York).**

parging. The first coat, called a scratch coat, should be roughened or scratched to form a mechanical bond with the finish coat. The scratch coat should be allowed to cure for at least 24 hours, then dampened immediately before applying the second coat. This finish coat should be troweled to form a dense surface, and a cove should be formed at the base of the foundation wall to prevent water from accumulating at the wall/footing juncture. The finish coat should be moist cured for 48 hours to minimize shrinkage cracking and assure complete cement hydration.

Mastic or bituminous dampproofing can be applied directly to the surface of concrete or masonry walls, but CABO requires that dampproofing on masonry walls be applied over a parge coat. If a parge coat is to be applied, mortar joints in masonry walls should be struck flush. If a bituminous dampproofing is to be applied directly to the masonry, the joints should be tooled concave. Mastic dampproof coatings can be either sprayed, troweled, or rolled onto the surface. Some contractors apply them by hand, smearing the thick, gooey mastic onto the wall with a glove. Cracks and voids such as form tie holes should be patched or filled before applying the dampproofing. The vapor permeability of the interior coating of a dampproofed concrete or masonry wall should be higher than the vapor permeability of the exterior coating so that construction moisture and any soil moisture vapor which permeates the wall can evaporate to the inside (Figure 6-39). Gypsum board and latex paint finishes work well, but vinyl wallcoverings will trap moisture in the wall.

There are two general methods of waterproofing. In *positive side waterproofing,* the waterproofing is applied to the same side of the wall or floor on which the water source occurs (Figure 6-40a). In *negative side waterproofing,* the waterproofing is applied on the opposite side of the structure as the water source (Figure 6-40b). Positive side waterproofing is always preferable because the structure itself is protected from moisture penetration, as well as the interior spaces. This is

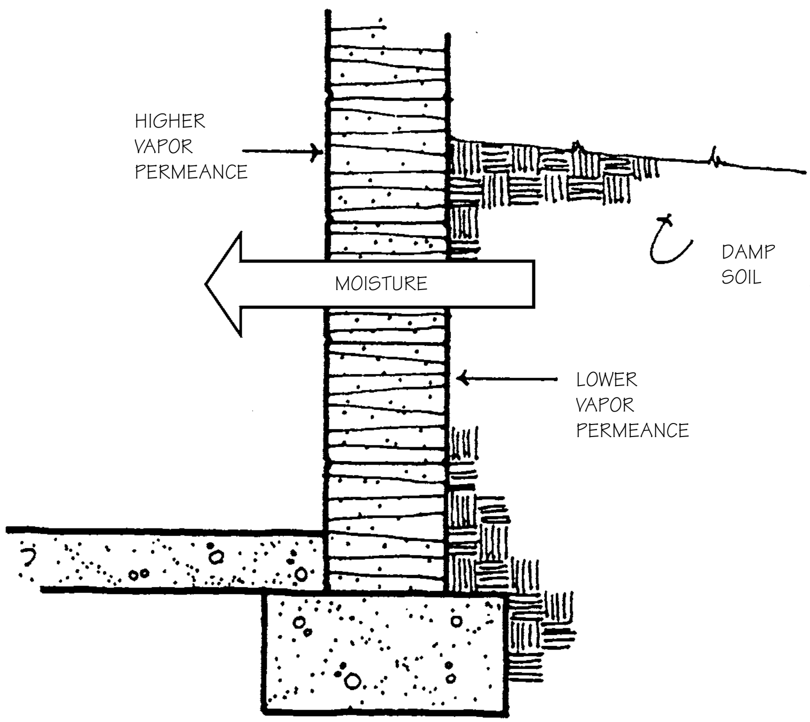


FIGURE 6-39

Vapor permeance. ***(from Beall, Christine,*** **Thermal and Moisture Protection Manual, McGraw-Hill, New York).**

particularly important when reinforcing steel may be corroded by prolonged moisture exposure or chloride contamination from the soil. Negative side waterproofing is generally used only as a remedial measure in existing buildings where outside excavation and repair are impossible or prohibitively expensive.

Since a waterproofing membrane must withstand hydrostatic pressure, it is critical that all holes, cracks, and openings in the wall be eliminated. This is easier to do below grade than it is in above-grade walls because of the absence of doors and windows, because there are fewer joints, because thermal expansion and contraction is less with smaller temperature variations, and because there is no ultraviolet deterioration of materials. Perfect barriers, however, are still difficult to achieve, and the barrier concept is very unforgiving of application errors. When combined with effective subsurface drainage, however, a waterproofing membrane can provide good performance even though human error will inevitably introduce minor flaws into the system. In wet climates, or on sites with high water tables, fluctuating water tables, or poor drainage, a waterproofing membrane should be used in addition to subsurface drains, free-draining backfill, or drainage mats.

FIGURE 6-40

Positive side and negative side waterproofing. ***(from Beall, Christine,*** **Thermal and Moisture Protection Manual, McGraw-Hill, New York).**

Waterproofing membranes must be fully adhered to the wall so that water cannot flow behind the membrane, and so that any leaks which occur will be easier to trace to the source. Membranes applied to concrete or concrete block must have sufficient flexibility to span cracks which will inevitably appear as a result of curing shrinkage, and enough elasticity to expand and contract with temperature changes. Steel reinforcement or control joints can be used to limit the amount of shrinkage cracking which will occur and to regulate the location of such cracks. If control joints are used, they must be sealed against water intrusion with an elastomeric sealant that will not deteriorate when submersed in water, that is chemically compatible with any membrane waterproofing or dampproofing which will be applied, and is resistant to any contaminants which may be present in the soil.

The CABO *One and Two Family Dwelling Code* requires waterproofing of foundation walls enclosing habitable space or storage from the top of the footing to the finish grade in areas where a high water table or other severe soil-water conditions are known to exist. Dampproof coatings are required in all other conditions. Waterproofing may consist of one of the following:

- 2-ply hot-mopped felts
- 55-pound roll roofing
- 6-mil polyvinyl chloride
- 6-mil polyethylene
- 40-mil polymer-modified asphalt

The joints in the membranes must be lapped and sealed with an adhesive compatible with the membrane itself. Dampproofing for masonry walls may consist of a 3/8-in. portland cement parging covered with one of the following:

- bituminous coating
- 3 pounds per square yard of acrylic modified cement
- 1/8-in. coat of surface bonding mortar, or
- any material permitted for waterproofing.

Concrete walls may be dampproofed with any of the dampproofing or waterproofing materials listed above. Waterproofing membranes must be protected from punctures and tears during the backfilling process. Some materials such as polyethylene sheets are particularly vulnerable to damage. Special protection boards can be erected over the membrane, or insulating drainage mats can be used for this purpose.

For wet soils with a high water table or a water table which may fluctuate seasonally or under severe weather conditions, and for deep foundations in multistory below-grade structures, Figure 6-41 illustrates appropriate drainage and waterproofing techniques. Slabs can be waterproofed in different ways, depending on the type of membrane being used. Horizontal membranes for below-grade slabs are often cast on a thin "mud slab" and the structural slab is then cast on top, or the membrane is installed on the structural slab and a topping slab added as a wearing surface. This provides a stable subbase to support the

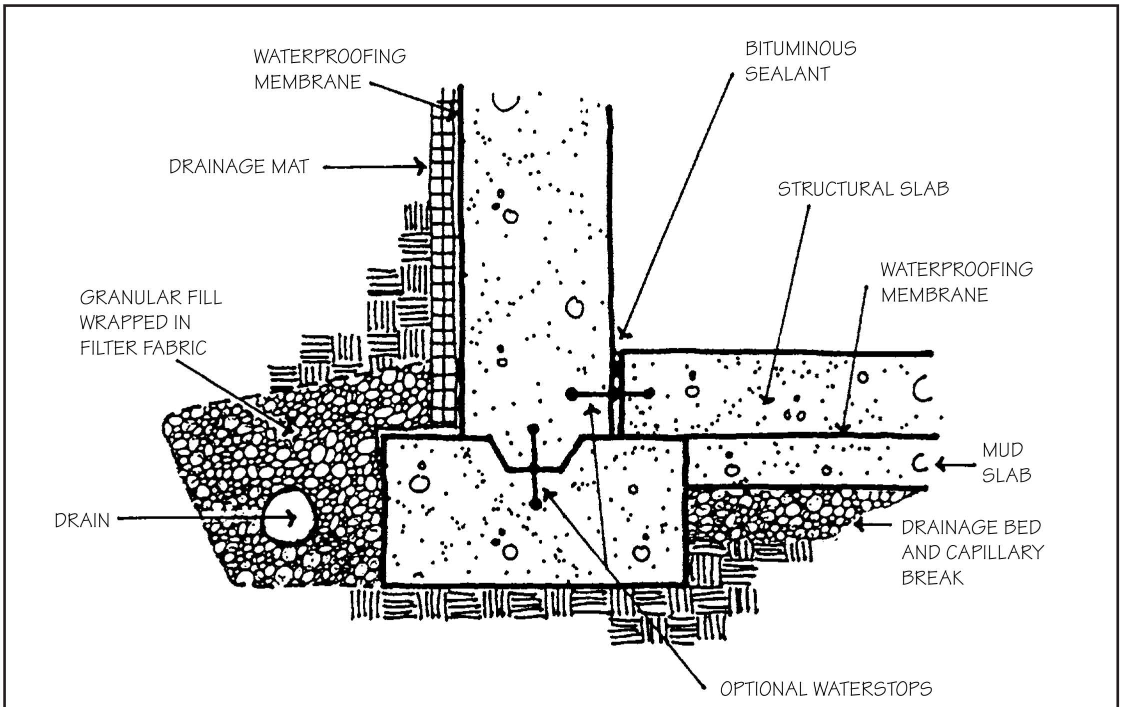


FIGURE 6-41

Waterproofing. ***(from Beall, Christine,*** **Thermal and Moisture Protection Manual, McGraw-Hill, New York).**

waterproofing and a protective wearing surface above it. Some types of waterproofing can be placed on compacted subgrade fill and a single structural slab cast on top of it.

6.6 Vapor Retarders

Where vapor migration from the soil is a potential problem, vapor retarders are necessary to protect the structure from a continuous flow of moisture. Where vapor-impermeable or moisture-sensitive floor-finishing materials are to be used, vapor retarders are particularly important in preventing loss of adhesion, peeling, warping, bubbling, or blistering of resilient flooring. Vapor retarders can also prevent buckling of carpet and wood flooring as well as fungal growth and the offensive odors and indoor air quality problems that accompany it.

In slabs-on-grade, polyethylene or reinforced polyethylene sheets of 6-, 8-, or 10-mil thickness are most commonly used in these applications. For maximum effectiveness, the vapor retarder must lap over and be sealed to the foundation; seams must be lapped 6 in. and sealed with pressure-sensitive tape; and penetrations for plumbing, electrical, or mechanical systems must be sealed. Vapor retarders under slabs-on-grade are usually installed over a base layer of free-draining gravel or crushed rock as a capillary break. Although vapor retarders themselves will prevent capillary moisture movement, they are usually used in conjunction with a drainage layer to provide a margin of safety in case of punctures or lap seam failures.

Figure 6-42 shows vapor retarder applications on basement slabs and slabs-on-grade. The granular base should be a minimum of 3 in. thick, and of compacted, mostly single-graded, coarse aggregate no larger than $^3/_4$ in. To protect the vapor retarder from puncture, a $^1/_2$-in. layer of fine, compactable sand fill may be rolled over the base. To keep the sand from settling into the gravel layer, a geotextile fabric can be placed over the coarse base material. Traditionally, a 2–4-in. layer of sand fill is added on top of the vapor retarder, but there are two schools of thought on whether this is necessary. In addition to providing a protection course on top of the vapor retarder, a layer of sand is thought by some to provide a cushion for the concrete and to act as a blotter to absorb excess moisture from the bottom of the slab. This supposedly promotes more even curing of the concrete, prevents exces-

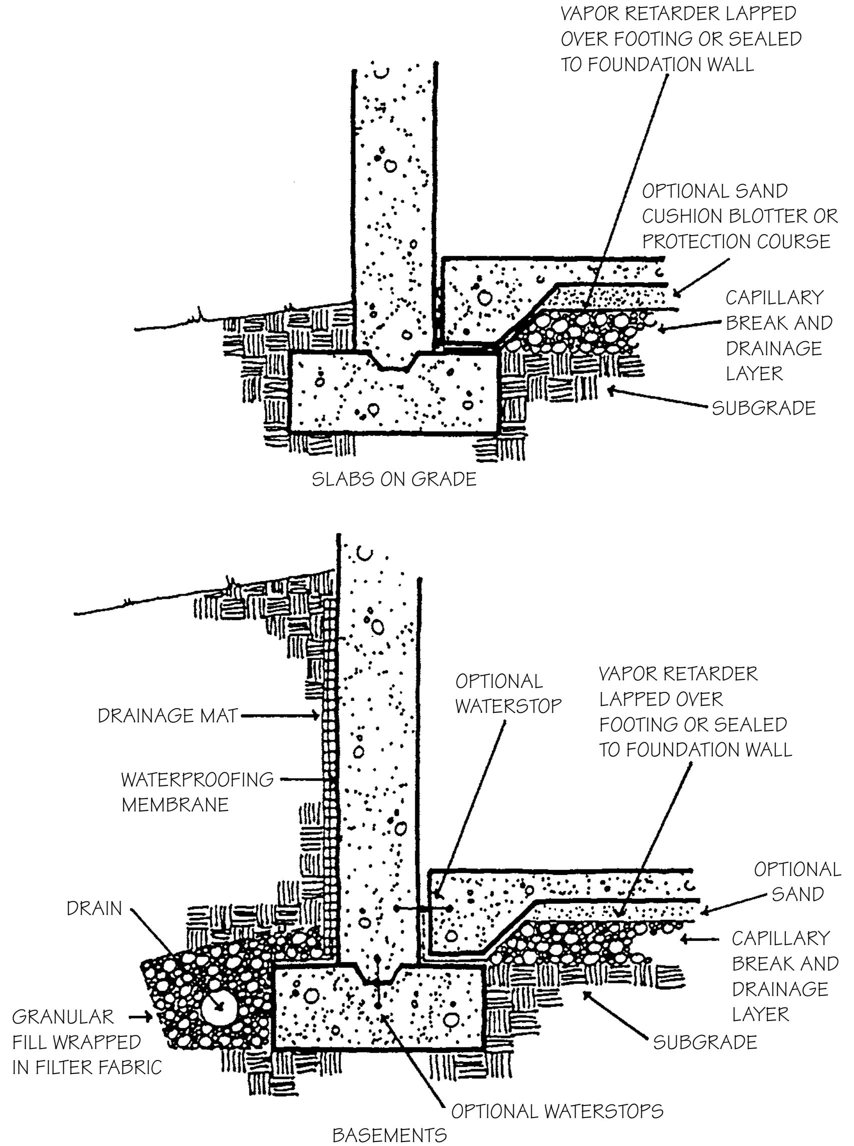


FIGURE 6-42

Vapor retarders. ***(adapted from ASTM E1643*** **Standard Practice for Installation of Water Vapor Retarders Used in Contact with Earth or Granular Fill Under Concrete Slabs.** ***Copyright ASTM).***

sive shrinkage cracking and slab curling, and permits earlier concrete finishing. Others feel that the vapor retarder can be better protected by a geotextile fabric rather than sand and that the blotter effect of the sand is not necessary to proper curing and finishing of the slab.

Reinforced polyethylene vapor retarders are more resistant to damage than unreinforced polyethylene and are manufactured in multiple plies for greater strength. If a sand cushion is not used, concrete mix designs should take into consideration the effect of a low-permeance vapor retarder on concrete curing, shrinkage, and drying time. Depending on the type of finish floor materials specified and the ambient conditions, concrete drying to acceptable moisture levels can take anywhere from 3 to 6 months. If scheduling is a potential problem, consider using a low-slump concrete so that there is a minimum amount of residual mixing water to evaporate after cement hydration has taken place.

6.7 Insulation

Soil is not a good insulating material, but it does have thermal mass which minimizes fluctuations in temperature. Daily temperature fluctuations affect only the top 1-1/2 to 2 ft. of soil. Annual temperature fluctuations affect the first 20–30 ft. of soil. Below this depth, the soil temperature is constant. Since average ground temperatures for most of the United States are below comfortable room temperatures, basements continuously lose some heat to the soil.

The thermal resistance of soil is generally estimated at R-1 to R-2 per foot of thickness. At an average of R-1.25, it takes 4 ft. of soil to equal the insulating value of 1 in. of extruded polystyrene insulation. Because heat flow from floor slabs and below-grade walls follows a radial path (Figure 6-43), however, the effective insulating value of soil is greater than would be initially apparent because the soil thickness is measured along the radial lines. This radial path of heat flow means that the perimeter of a slab-on-grade is subject to much greater heat loss than the interior floor. Figure 6-44 shows the heat flow from the perimeter of a floor slab to a cold exterior ground surface as a series of nearly concentric radial lines. As the length of the heat flow path increases, the effective insulating value of the soil increases, so thermal insulation is generally required only at the perimeter of the slab and not under the entire floor area. Placing this insulation vertically on the outside of the foundation provides the greatest protection from freeze-thaw stresses. Recommended R-values for perimeter insulation are shown in Figure 6-45.

Heat loss from a basement includes that which takes place through the wall above grade and that which takes place through the wall and floor below grade. In addition, there is heat loss in the movement of air. There is a potential path of significant air leakage through the joint between the top of the basement wall and the sill plate of the superstructure. With a hollow concrete block wall, part of which is exposed above grade, air in the block cores is cooled and sinks by convection, displacing warmer air in the lower parts of the wall. This causes additional heat loss from the basement as the lower portions of the wall are cooled. Insulating the outside of the wall will minimize this effect, and grouting the wall will eliminate the convective air spaces. Except in extreme northern climates where the ground temperature is colder, it is usually necessary to insulate only the first 3 to 6 ft. of below-grade

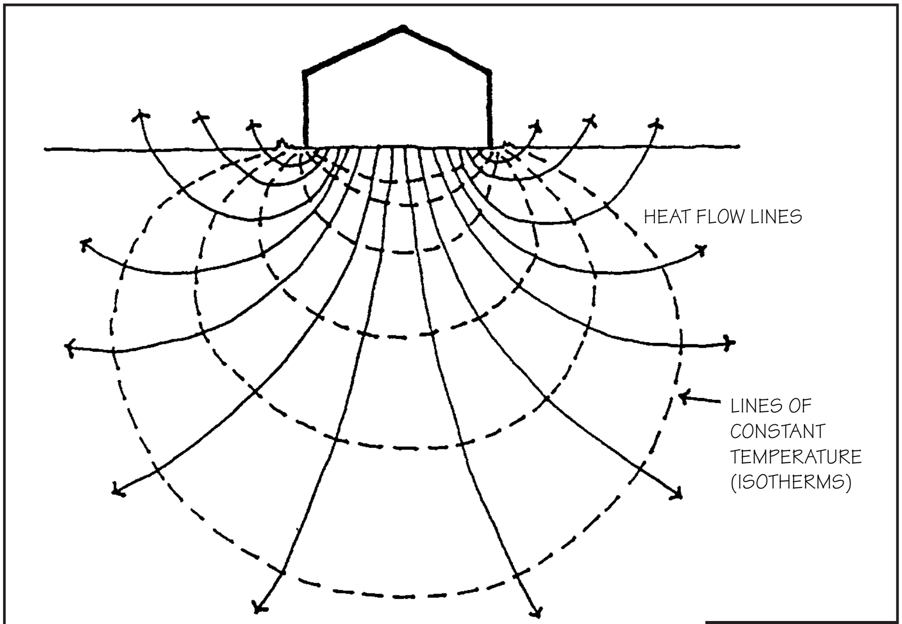


FIGURE 6-43

Radiant heat loss to soil. ***(from Donald Watson and Kenneth Labs,*** **Climatic Building Design,** ***McGraw-Hill, 1983).***

walls. Below this level, the cumulative thermal resistance of the soil is sufficient to prevent serious heat loss.

6.8 Frost-Protected Shallow Foundations

Deep foundations required to reach below the frost line add cost to the construction of homes. Some codes, including the CABO *One and Two Family Dwelling Code* allow the construction of shallow slab-on-grade foundations for heated buildings in cold climates if certain precautions are taken to protect against frost heave. This type of foundation design is sometimes referred to as frost-protected shallow foundations, insulated footings, or frost-protected footings and was first developed in Scandinavia.

A layer of polystyrene insulation applied to the vertical stem of the foundation wall, and a horizontal "wing" of insulation placed outside

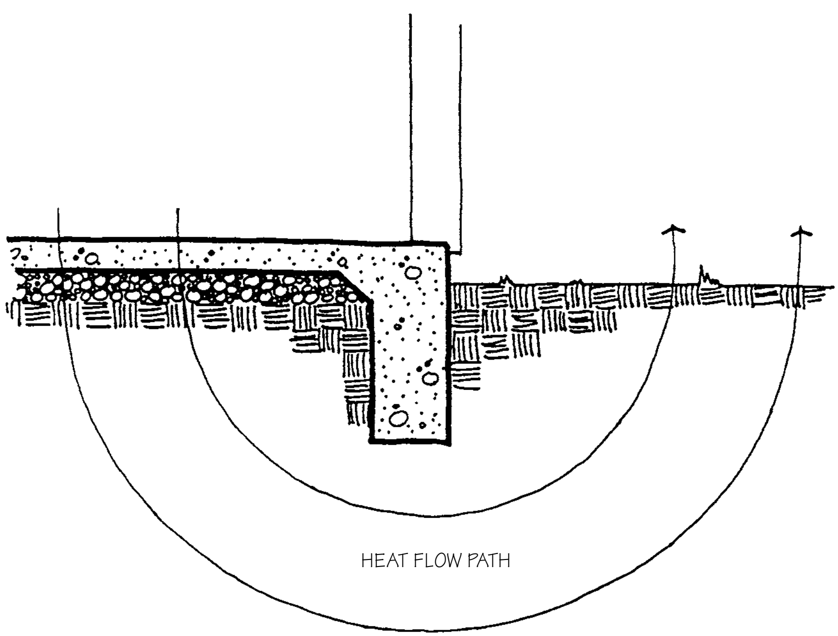
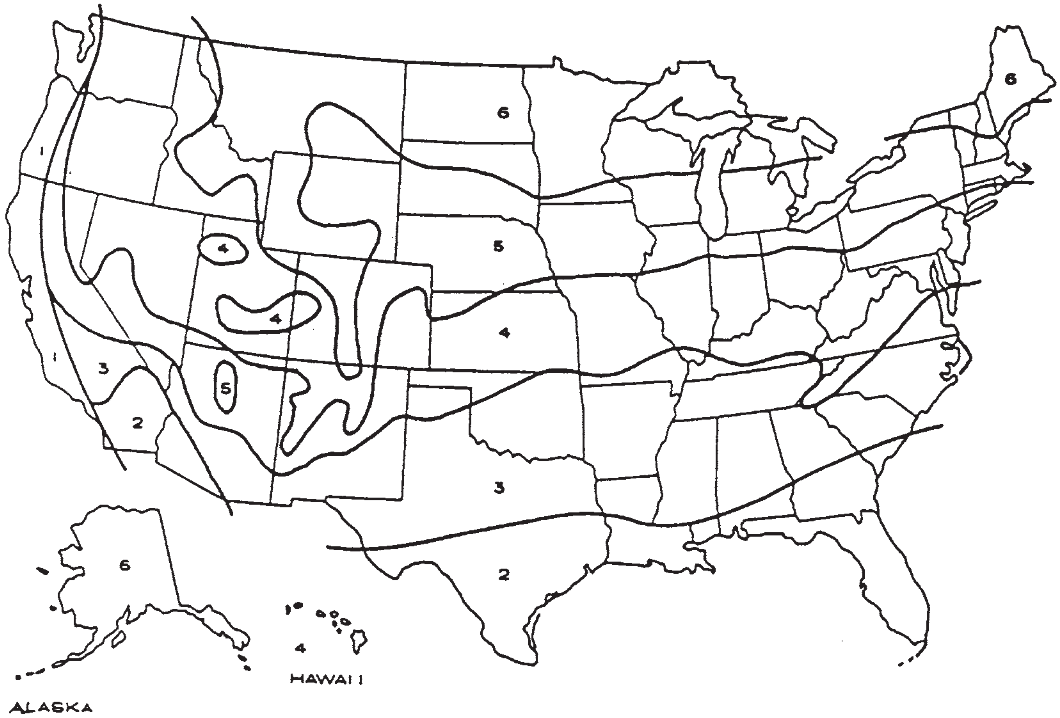


FIGURE 6-44

Heat loss at foundation perimeter. ***(from Donald Watson and Kenneth Labs,*** **Climatic Building Design,** ***McGraw-Hill, 1983).***



RECOMMENDED MINIMUM THERMAL RESISTANCE (R) OF INSULATION

ZONE	CEILING	WALL	FLOOR
1	19	11	11
2	26	13	11
3	26	19	13
4	30	19	19
5	33	19	22
6	38	19	22

NOTE: The minimum insulation R values recommended for various parts of the United States as delineated on the map of insulation zones.

FIGURE 6-45

Recommended R-values. ***(from*** **Architectural Graphic Standards,** ***9th ed.)***

the perimeter of the building effectively blocks the natural radial heat flow paths (Figure 6-46). Heat migrating from the building interior elevates the soil temperature above its winter norm and artificially raises the frost depth. Seasonally fluctuating temperatures eventually stabilize since the heat cannot escape to the exterior ground surface. Code requirements for the use of frost-protected footings are based on climatic conditions. The air-freezing index in Figure 6-47 indicates the magnitude and duration of winter conditions in various parts of the country. The table and diagrams in Figure 6-48 list Code requirements for R-value and insulation dimensions based on air-freezing index ratings.

6.9 Ventilation and Radon Protection

Crawl spaces must be ventilated to dissipate soil moisture vapor and prevent its being drawn into the home. This means providing openings in the foundation walls of sufficient size and number to meet code

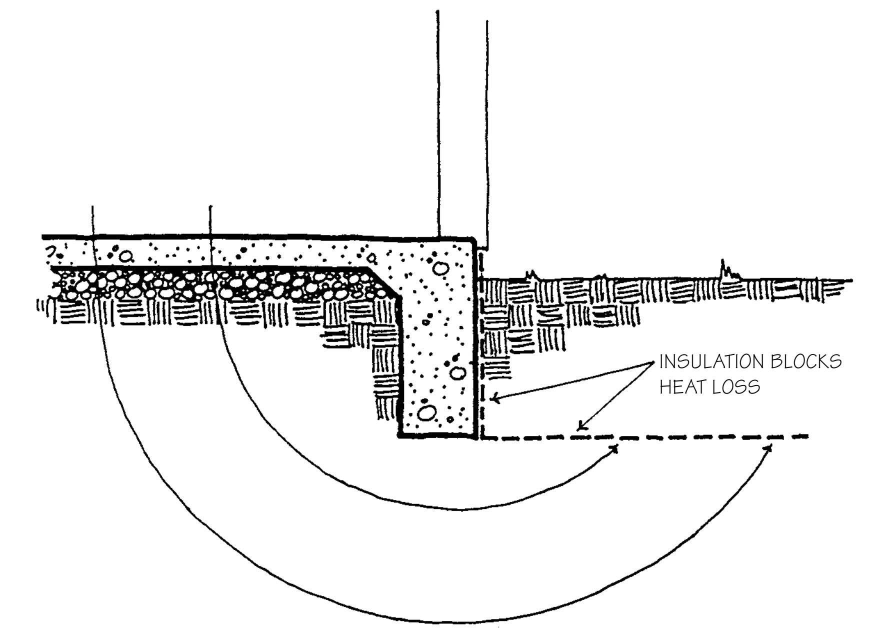
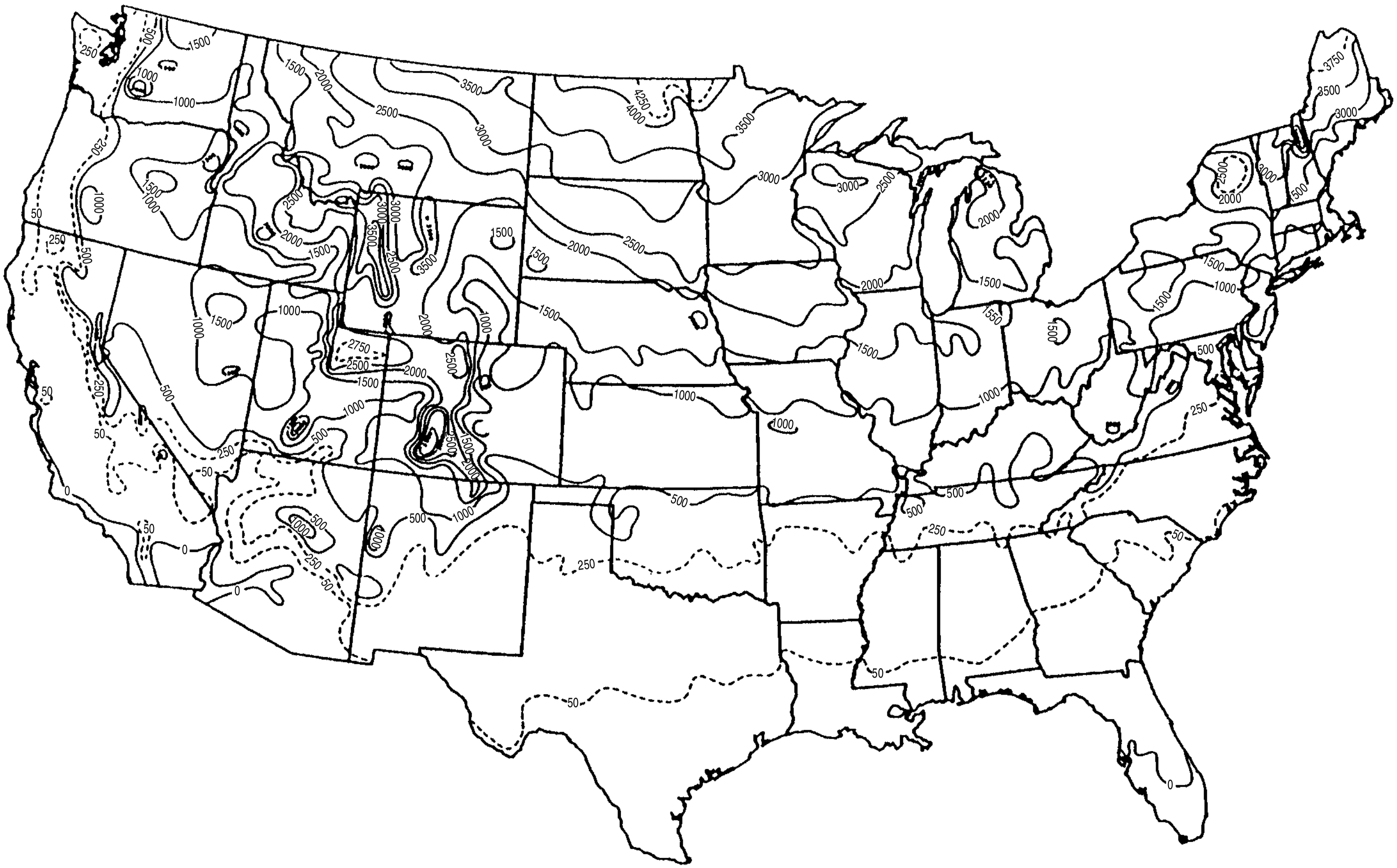


FIGURE 6-46

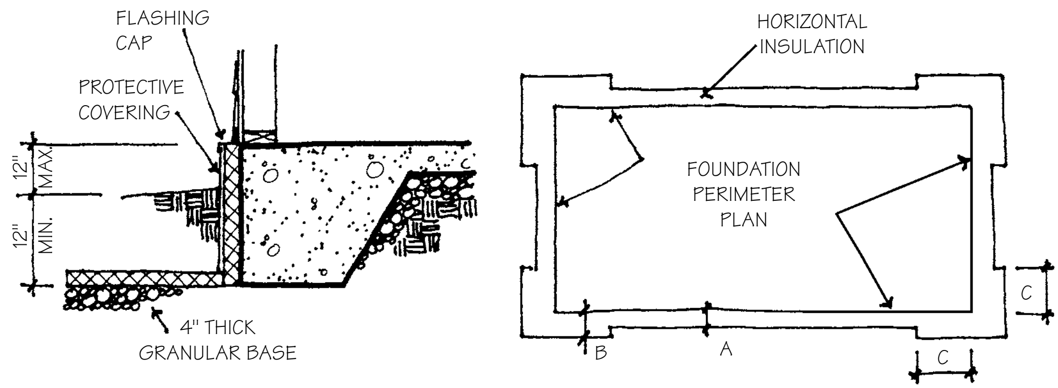
Frost protected footings.



The air-freezing index is defined as cumulative degree days below 32°F. It is used as a measure of the combined magnitude and duration of air temperature below freezing. The index was computed over a 12-month period (July-June) for each of the 3,044 stations used in the above analysis. Data from the 1951-80 period were fitted to a Weibull probability distribution to produce an estimate of the 100-year return period.

FIGURE 6-47

Air freezing index. *(from Council of American Building Officials* **One and Two-Family Dwelling Code,**, *Falls Church, VA)*.



Minimum insulation requirements for frost-protected footings in heated buildings[1]

Air Freezing Index (°F Days)[2]	Vertical Insulation R-Value[3,4]	Horizontal Insulation R-Value[3,5] along walls	Horizontal Insulation R-Value[3,5] at corners	Horizontal Insulation Dimensions Inches A	B	C
1,500 or less	4.5	Not Required	Not Required	Not Required	Not Required	Not Required
2,000	5.6	Not Required	Not Required	Not Required	Not Required	Not Required
2,500	6.7	1.7	4.9	12	24	40
3,000	7.8	6.5	8.6	12	24	40
3,500	9.0	8.0	11.2	24	30	60
4,000	10.0	10.5	13.1	24	36	60

NOTES:
1. Insulation requirements are for protection against frost damage in heated buildings. Greater values may be required to meet energy conservation standards. Interpolation between values is permitted.
2. See Figure 6-47 for Air-Freezing Index values.
3. Insulation materials shall provide the stated minimum R-values under long-term exposure to moist, below-ground conditions in freezing climates. The following R-values shall be used to determine insulation thickness required for this application: Type II expanded polystyrene 2.4 R per inch; Type IV extruded polystyrene 4.5 R per inch; Type VI extruded polystyrene 4.5 R per inch; Type IX expanded polystyrene 3.2 R per inch; Type X extruded polystyrene 4.5 R per inch.
4. Vertical insulation shall be expanded polystyrene insulation or extruded polystyrene insulation, and the exposed portions shall have a rigid, opaque and weather-resistant protective covering to prevent the degradation of thermal performance. Protective covering shall cover the exposed portion of the insulation and extend to a minimum of 6 in. below grade.
5. Horizontal insulation shall be extruded polystyrene insulation.

FIGURE 6-48

Minimum insulation requirements for frost-protected footings in heated buildings[1] ***(from Council of American Building Officials*** **One and Two-Family Dwelling Code,*, Falls Church, VA)*.**

requirements for crawl space ventilation. A minimum of four openings should be provided (one at each corner), placed as high in the foundation wall as possible. The CABO *One and Two Family Dwelling Code* requires a minimum net area of ventilation openings of 1 sq. ft. for each 150 sq. ft. of crawl space area, with one opening located within 3 ft. of each corner. Ventilation openings must be provided with corrosion-resistant wire mesh with the least dimension of the mesh being 1/8 in. Net and gross ventilator areas for different types of screens and louvers are given in Figure 6-49. After calculating the required net area, multiply by the coefficient shown to determine the overall size or gross area of ventilators needed. Ventilation will dissipate soil moisture vapor, but it also will cool the underside of the floor sufficiently to require insulation to prevent winter heat loss. An alternative control measure is to cover the exposed soil. With a vapor retarder of polyethylene film, heavy roll roofing (55 lb.), or a proprietary membrane, the required net area of ventilation may be reduced to 1 sq. ft. for each 1,500 sq. ft. of crawl space area. Vents still should be placed within 3 ft. of each corner but may be omitted entirely from one side of the building.

In concrete foundation walls, blockouts can be provided for crawl space ventilation openings using either plywood or lumber to frame a penetration of the correct size through the formwork. Make sure the concrete flows around and fills in underneath the blockout by mechanical vibration or hammering against the forms. In concrete

Ventilator covering	Coefficient
1/4″ mesh hardware cloth	1
Screening, 8 mesh.in.	1.25
Insect screen, 16 mesh/in.	2
Louvers plus 1/4″ mesh hardware cloth	2
Louvers plus screening, 8 mesh/in.	2.25
Louvers plus insect screening, 16 mesh/in.	3

*Gross ventilator area = required net area × coefficient

FIGURE 6-49

Net and gross ventilator area.

block foundation walls, screen block of the type described in Chapter 9 may be used if they are properly fitted with screen wire on the inside of the wall. An 18 in. × 24 in. minimum access opening must also be provided through the foundation wall to permit servicing and inspection of underfloor areas.

Where a crawl space is provided below wood-framed construction, the wood should be separated from the exposed soil by the minimum distances shown in Figure 6-50. In addition to separating the wood framing from the vapor source and allowing for ventilation, these clearances assure adequate access for periodic visual inspection. All formwork from footing and wall construction should be removed before proceeding with construction. The Code permits the finish grade in the crawl space to be at the bottom of the footings unless there is evidence of a rising water table or inadequate surface water drainage. In these cases, the finish grade in the crawl space must be the same as the outside finish grade unless an approved drainage system is provided.

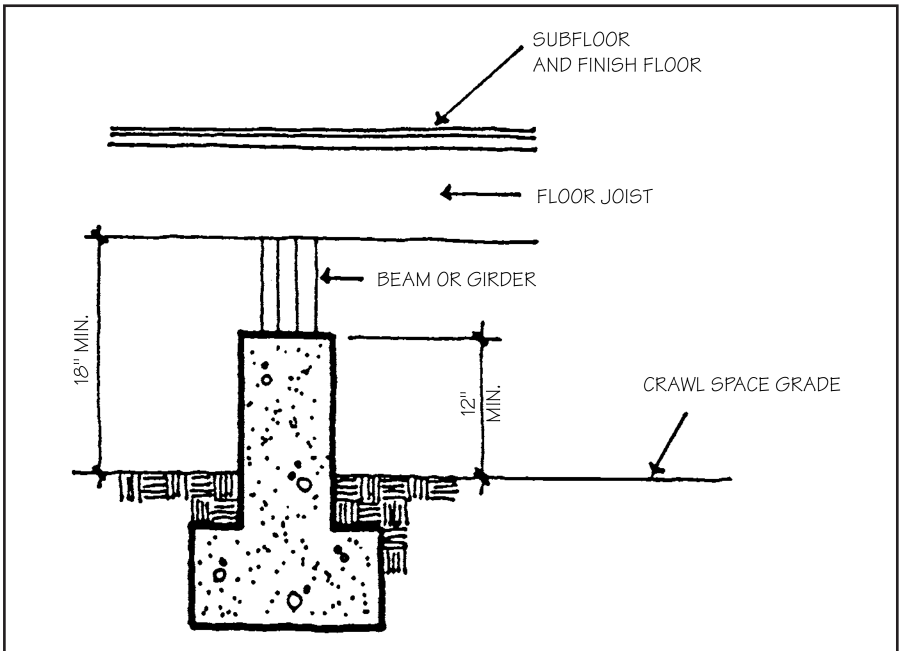


FIGURE 6-50

Minimum height of wood framing above crawl space soil. ***(from Beall, Christine,*** **Thermal and Moisture Protection Manual, McGraw-Hill, New York).**

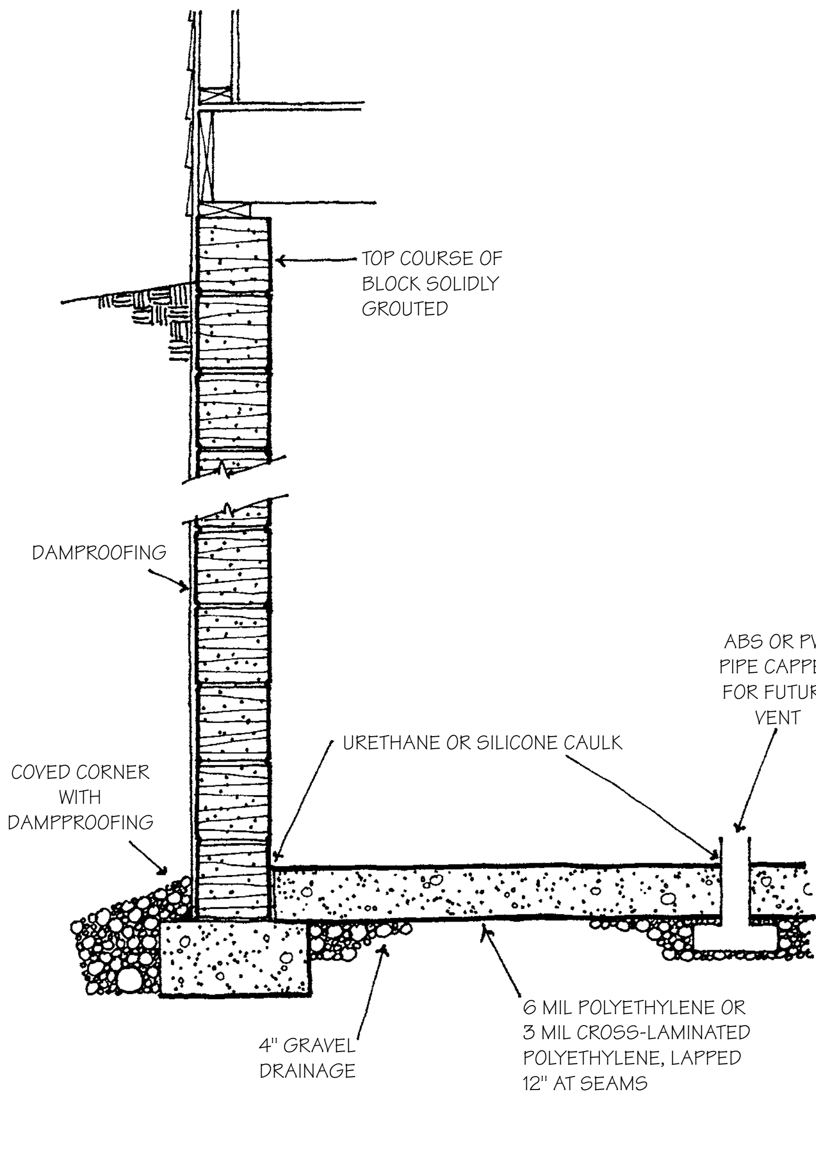


FIGURE 6-51

Radon protection. ***(from NCMA*** **TEK 6-15,** ***National Concrete Masonry Association, Herndon, VA).***

In areas where radon gas from the soil is a potential problem, most building codes require that basements, crawl spaces, and slabs-on-grade be designed to resist radon entry and that the building be prepared for post-construction radon mitigation, if necessary. Figure 6-51 shows CABO requirements for basement construction. Similar details apply to crawl space and slab-on-grade foundations. One of the primary considerations is sealing the walls and slab to prevent gas entry. Dampproofing, perimeter caulk, and a below-grade air barrier are important elements. A 6-mil polyethylene sheet or a 3-mil cross-laminated reinforced polyethylene sheet is acceptable for this use. The top course of hollow concrete masonry foundation walls must be grouted solid to prevent air leakage to the interior space above, and a 4-in. layer of gravel below the slab acts as a gas-permeable layer which can be mechanically vented if needed. All control joints, construction joints, and isolation joints in concrete and masonry must be caulked.