Foundations: Structural Basics

Photo courtesy of Western Forms, Inc.

by Paul Hanke

A firm foundation is essential to a building's longevity and stability. To succeed structurally, a foundation must perform several functions at once. It must transmit vertical loads to bearing soil; distribute those loads over a large enough area; resist lateral forces, cracks, and leaks; and anchor the building against uplift.

Carrying the Load

Transmitting both live and dead loads downward is a foundation's first job. To do this, a foundation wall or column must be plumb and have enough *compressive* (crushing) strength to resist the vertical forces imposed on it. Concrete resists such compressive forces easily; typical strengths range from 2,500 to 4,000 pounds per square inch (psi)—more than enough. A typical poured-concrete foundation wall illustrates these functions (see Figure 1).

The foundation wall transfers building loads vertically to the footing below, where—according to physics—they must be resisted by an equal and opposite reaction from the soil. Otherwise, the building will settle, with possible disastrous consequences.

Footings

The footing in a conventional foundation distributes the weight of the building over a large enough area of soil to prevent settling. It keeps a building from sinking in soft soil in the same way that a snowshoe holds you up in soft snow.

The first line of defense against settling is to pour the footings on undisturbed soil. Excavation can turn earth in the bottom of a trench, and everyone knows what happens when you walk on freshly turned earth: you sink in a bit. All loose soil must be mechanically compacted, or removed and replaced with concrete.

Beyond that, the soil must be strong enough to resist the loads imposed on it. Gravel and sand are relatively strong (typically, 4,000 to 8,000 psf), and also quite permeable, allowing water to drain rapidly.

Clays, on the other hand, are weaker and not very permeable—and therefore trap and hold soil moisture. When they get wet, clays swell; when they dry, they shrink—by as much as 25 percent. This can spell disaster. If clay soil is present, good drainage is essential. Use drain tiles and porous backfill, and have a finished grade that slopes away from the building.

Sizing Footings

A rule of thumb for sizing residential footings states that the footing should be twice as wide and equally as thick as the foundation wall (Figure 2). To determine whether your footing size is adequate, you must know the total load that will be imposed on each lineal foot, and the bearing capacity of the soil below.

A typical example might be the two-story house shown in the illustration. Here, half the floor loads and all of the roof load for one side of the building are transferred to the foundation wall. The central girder carries the other half of the floor load and transfers the load to individual column footings. In addition, the concrete walls and footings themselves weigh about 150 pounds per cubic foot. The total design load we have to support adds up to 2,074 pounds per running foot.

If we assume a modest soil-bearing capacity of 4,000 psf, we need half a square foot of soil (2,074 divided by 4,000) to support each lineal foot of wall. A typical 16-inch-wide footing provides 1.33 square feet per lineal foot, which offers an ample safety factor of 160 percent. For larger loads or poorer soils, the footing could be increased to 18, 20, or 24 inches. Much beyond that, though, footings begin to act as beams, and need engineering analysis and special reinforcement.

Concentrated loads, such as chimneys and Lally columns, need their own footings—either a separate pour or a thickened section of the slab. Chimney footings typically extend six inches beyond the chimney base and are 12 inches thick but, like post footings, should be sized for the load they carry. I like to reinforce in all cases with No. 4 rebar, 12 inches on center each way

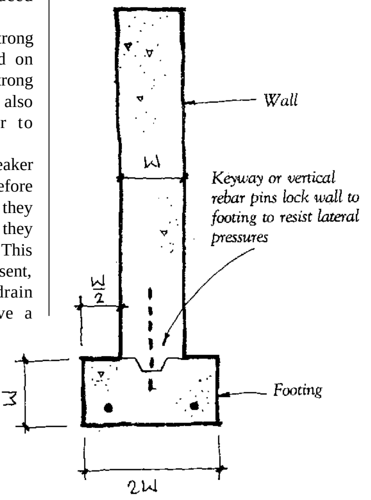


Figure 2. Typical Foundation Construction

Figure 1. A foundation must (1) support and distribute vertical loads from above, (2) support concentrated loads, (3) resist lateral forces, (4) anchor the building against uplift

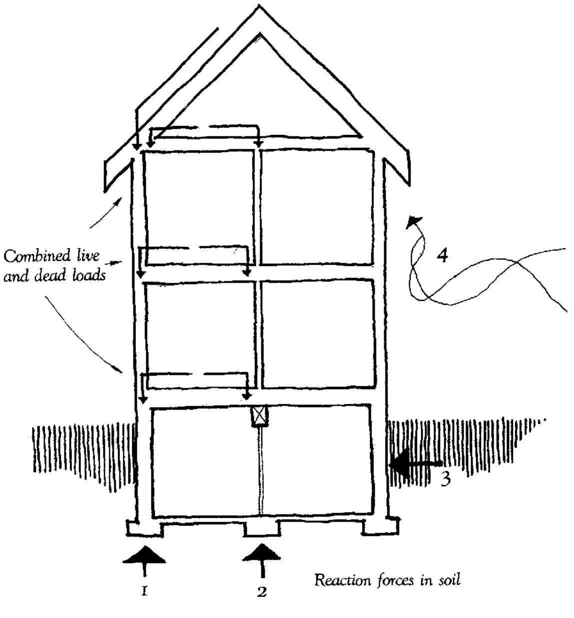
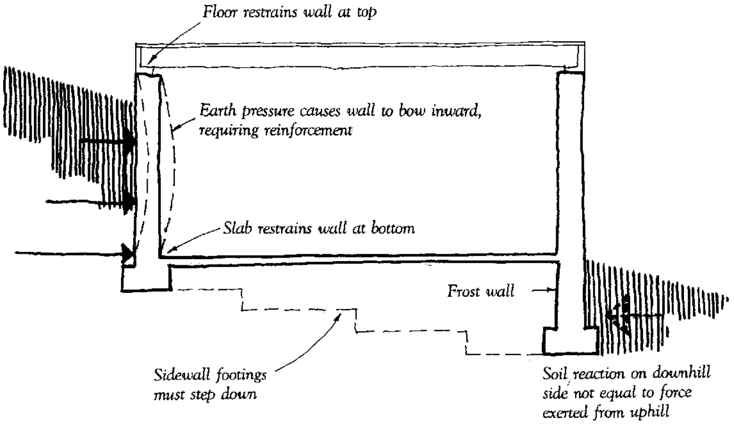


Figure 3. Hillside Foundation



RETHINKING REBAR

by Harris Hyman, P.E.

"Good practice" generally says to put reinforcing bar into concrete foundations. Like most principles of construction, however, good practice varies from one foundation contractor to the next—from rigid specifications for lots of steel to no steel at all. Despite these variations, there are relatively few failures with poured foundations.

So what is a reasonable approach to reinforcing the foundations of light-frame buildings?

The Actual Load

A frame building weighs approximately 40 to 50 pounds per square foot of floor area. A typical 24x40-foot house with two floors and a basement will weigh in at about 144,000 pounds. If an eight-inch foundation wall is used around the 128-foot perimeter, all of the weight rests on 85.2 square feet, or 12,276 square inches. The load on each square inch of concrete is only 11.7 pounds. Since foundation concrete is usually transit-mixed for a compressive-stress load of 2,500 psi, the wall is loaded to less than *half of one percent* of design capacity!

Let's look at another situation—a 40-foot-tall chimney. A 16x28-inch chimney would weigh 18,667 pounds if it were solid concrete. There are, of course, flue holes and concrete-block cavities, so this is a severe overestimate. But even so, the load is only 41 psf—less than 2 percent of the capacity of the concrete.

Rebar and Cracking

The arithmetic suggests that the rebar in foundations is *not* to give it strength to withstand the load of the house. The rebar has a radically different purpose: to control cracking when the foundation moves, Rebar holds the pieces of the foundation together when it cracks, and it helps stop cracks from spreading.

The actual load on foundations is somewhat irregular and the soil movement under the building is irregular, so different parts of the foundation move at different rates. When this happens, the foundation breaks up a little and the rebar holds the parts together. The small amount of lightweight rebar used in residential foundations will generally not prevent cracking. Forces that are great enough to crack the wall will bend or snap the rebar.

However, since the rebar for our 24x40-foot house costs only about $200, and it makes everybody feel good, why not install it like everyone else does?

The sketch shows conventional rebar practice throughout most of northern New England. You could save material by spacing the horizontal rebar 24 inches on center rather than 16 inches apart, but it's more convenient to rest the bars on the ties, which are spaced every 16 inches.

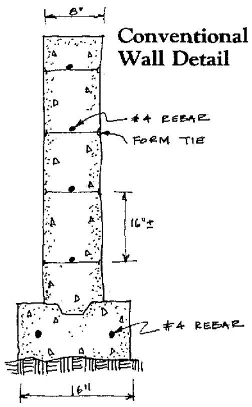
The second sketch shows a slightly more rational practice: using 4x4x1/4-inch welded-wire mesh. This provides somewhat better control over cracking, but is quite a bit more expensive than the 1/2-inch rebar, so it's not generally used.

Another alternative is 6x6-inch 10-10 welded-wire mesh. Although not particularly expensive, it is a mess to install the soft, wiggly wire and keep it somewhere near the middle of the wall, so this technique has not achieved much popularity.

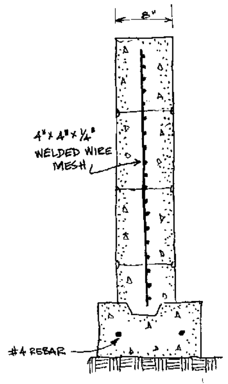
The 6x6-inch 10-10 mesh is widely used for slabs. The conventional slab detail shown in the sketch has a thickened edge and two pieces of rebar, which will keep most jobs out of trouble. Slabs also have extremely light loads, but have more chance of cracking because more surface area rests on the earth.

The Purpose of Footings

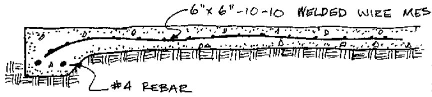
By the way, the sketches show rebar in the footings. Although this is conventional practice, it is not really necessary, either. The purpose of footings themselves is generally misunderstood, even by my very favorite authority on building, Willis Wagner. *(Modern Carpentry,* published by Goodheart-Willcox, should be part of everyone's library.)



Conventional Wall Detail



Better Wall Detail



Conventional Slab Detail

The footing is *not* for distributing loads to the soil. Even medium clay soils will hold three tons per square foot, or 42 psi. From our calculations above, we know that this is approximately the stress at the base of a 40-foot masonry column, so there is little need to spread out the load. Instead, the purpose of footings is to provide a smooth, level base for formwork, concrete-block walls, or chimneys and fireplaces. Again, no rebar is really needed, but it is inexpensive and easy, so why not throw it in?

Footings that support long block walls are a little more critical, since unit masonry has relatively little strength compared to poured walls. I use the term "long" to mean walls that are more than twice as long as they are high. These should have some reinforcing, such as steel ladder, every third or fourth course, since cracks propagate right up the joints and are quite visible. In poured walls, cracks tend to be fine and almost invisible.

A Better Method

If the purpose of reinforcing in light-frame buildings is to control cracking, why nor use a better method? I believe that monomeric plastic fiber provides a far better system [see "Fibermesh Magic,"] and I personally specify it for all frame-building foundations.

These suggestions about foundation reinforcing have their limitations. First and foremost, remember that this discussion applies to foundation reinforcement, not to structural concrete, which is an entirely different problem.

Next, these suggestions apply only to frame buildings that are not over three stories high, or brick or unit-masonry buildings not over two stories high. This excludes steel-frame, prefab industrial buildings, which often place heavy stresses at the foot of supporting columns.

Third, the buildings must be constructed on reasonable soils; loose sand and soft clay are special situations well outside of these suggestions.

Fourth, it is assumed that the buildings support floor loads of no more than 150 psf, and have no serious point loads such as machinery.

Finally, the suggestions are not applicable in earthquake areas—not a particular problem in New England. For general light construction, however, these guidelines are reasonable. ■

(parallel to the base of the footing).

Lateral Forces

The earth not only resists the vertical loads imposed by the building, it also exerts sideways (lateral) forces of its own, which the foundation must resist. In unfrozen ground, these loads are smallest near the surface and increase as you go deeper (just like water pressure in scuba diving).

Lateral force is the reason you should never backfill a foundation until the first floor is framed—the floor keeps the tops of the foundation walls from toppling, while the keyway, vertical rebar pins, or slabs do the same at the bottom.

In winter, another lateral force is created by frozen soil, which is one reason why good drainage is so important. The soil freezes hardest near the surface (particularly where perimeter insulation is used), but frozen soil at any depth can exert enormous pressure.

If you don't think frost can push things around, consider the three-story, solid-brick chimney—with a couple of fireplaces—that I saw recently in an unfinished, unheated building in central Vermont. Over the course of one winter, it had risen two inches on its footing and come back down. No harm was done since the chimney went straight up through the hole in the roof, and came straight down again! The results could have been much worse had the movement been absorbed elsewhere. (Glass, in particular, doesn't like unequal forces placed on it.)

A final note: Where excessive lateral forces are expected—for example, from earth pressure, expansive clays, or frozen soil—the walls should be reinforced with both horizontal and vertical rebar. [See sidebar.] This is true for some walkout-style foundations, where there is less resisting force on the opposite side of the building, and for walls that are cut into hillsides (Figure 3). In extreme cases, a retaining wall may have to be used.

Uplift

In addition to resisting downward and sideways forces, a foundation must perform one other structural function. When wind blows against and over a building, it tries to tip and lift the building off its moorings. Keeping the two together is the reason the sill is bolted to the foundation. Bolts are typically placed six feet on center, and within 12 inches of all corners and openings. I prefer them every four feet, which, I find, makes it easier to level the sill.

Make sure you leave enough exposure (minimum two inches) for the bolt to clear the top of the sill, or the carpenters will have to chisel it, which is a real pain and weakens the connection. Don't place bolts too close to the edge of the sill, Read the drawings to determine the size of the sill and whether it will be offset to the outside to overlap foundation insulation.

Frost Depth

Frost depth varies from place to place. As a rule of thumb, the American Institute of Architects recommends that footings be placed 12 inches below the local frost depth to prevent damage due to heaving. I live in central Vermont, where the average frost depth is four feet. But when you have a relatively snowless winter, the ground can freeze much deeper and things that haven't moved for years start to shift around.

A typical full basement with 8- to 12-inch exposure at the top is probably safe in most locations, except where a sloping site brings you to or near grade level on one side. In such cases, the footing must step down as necessary to create a “frost wall” on the low side (Figure 3). This is true with a walkout also.

Foundation Types

In New England, the full basement (or cellar, as in “down-cellah”) is the traditional choice. An eight-foot wall gets you below frost in most cases, and poured concrete is a cheap way to enclose space (at least until you finish it off). On the other hand, underground spaces can (to paraphrase architect Malcolm Wells) be damp, dark, slithery, slimy, and smelly.

Crawl spaces are less expensive, but you sacrifice usable space and some measure of resale value. However, an insulated crawl space can be used for heat distribution, as in the APA plenwood system, which will save the cost of ductwork.

A mini perimeter wall without footing, called a grade beam, can be supported either on piers or by a gravel trench. (This was widely used by Frank Lloyd Wright.) The crushed stone in the gravel trench supports and distributes the building load and provides excellent drainage, which prevents frost heaving.

Pier foundations (concrete or treated-wood poles) are well suited to post-and-beam buildings, but they require careful detailing and reinforcement in frost country, and the floor must be insulated and protected from wind. Vertical reinforcement is especially important—I have seen piers snapped off at grade by unequal ground freezing. Also, the pier should be tied to the footing with rebar to resist uplift from wind or frost.

Finally, so-called floating slabs are used most often for commercial work, but they also offer an economical alternative for residential construction on flat sites. Like the gravel-trench method, the slab “floats” on a two- to three-foot layer of well-drained sand or compacted gravel fill that extends beyond the building perimeter. [See “Floating Slabs for Unheated Buildings”.] Good drainage combined with perimeter insulation provides frost-proofing. This is another cost-saver, especially for passive-solar houses, where the slab also soaks up the sun’s energy.

Any of these systems, properly done, can provide a sound and long-lasting foundation. But there is no single solution that is right for all jobs.

For example, I once designed and built a summer place here in Vermont for a couple from Boston. Because of unknown groundwater conditions, and for economy’s sake, I designed the building with a crawl space and with a network of piers under the porch. As construction began, the excavator and concrete sub talked the owners into a full basement. In fact, the excavator, an old-timer who I otherwise liked very much, said to me, “You ought to be hanged from a tree [for all those piers]. We don’t use them up here.”

Well, when I left the job in mid-January, there was eight inches of ice in that cellar, despite a functioning drain tile. We’ll never know if my design would have done any better, but the conventional way isn’t always the best way. ■

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