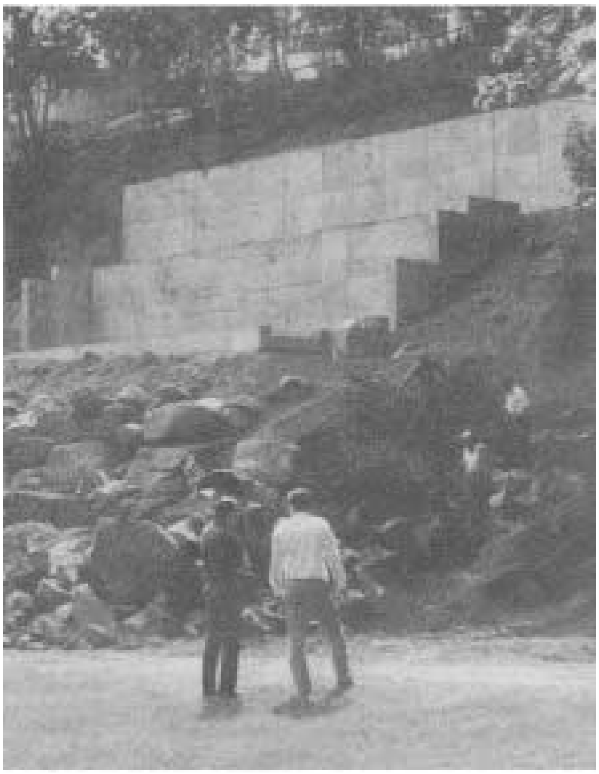
# STEEP-SITE SOLUTIONS

BY P. JAMES ROLAND

## Straightforward ways to meet the high demands of hillside foundations



*A two-tiered slab on stepped footings enabled the builder to fit two townhouses onto this steep and narrow urban site.*

As the number of prime building sites decreases in New England and elsewhere, more builders are forced to choose difficult sites. One common problem is a steep grade. While some solutions to steep sites draw on systems more familiar to commercial builders, residential builders generally fare best if they stick with materials and techniques familiar to them. But all solutions require a higher level of sophistication than flat-site building, and all will add to the cost.

In light frame construction, there are two types of steep building sites: those that slope away from the building (downward sloping) and those that slope toward the building (upward sloping). Even though both types involve building into the hillside, each type poses different problems to the builder.

### Materials

In New England, it's normal to see unreinforced concrete basement walls on unreinforced continuous strip footings. Both materials can serve on steep sites. But if the wall retains more than 4 feet of soil or is of above-average height, the concrete blocks must be reinforced with steel bars and the voids filled with grout. Cast-in-place concrete walls will also need reinforcing if they retain more than 4 feet of soil.

Rubble walls are not practical for any modern foundation. In fact, the Mass. State Building Code prohibits the use of brittle or nonhomogeneous walls because they would be unpredictable in an earthquake. Areas of both New Hampshire and Rhode Island are considered to be in earthquake zones as well.

### Soil

Steep sites require deeper excavation on the uphill side–creating much greater soil forces. Many people do not realize that a 10-foot wall of earth exerts twice the horizontal force of an 8-foot wall. A 12-foot wall exerts over three times the force of an 8-foot wall (the force is proportional to the height cubed).

The greater forces make the excavation much less stable during construction than a shallower cut. They also require heavier foundation systems to resist the greater soil loads.

Soil that has not been analyzed by a geotechnical engineer is generally assumed to exert a pressure of 40 pounds per square foot (psf) per foot height of pressure against a basement wall. Actually, this varies greatly depending on the type of soil and the amount of water it holds, not only during building hut for the life of the structure. Soil pressure can vary from zero, for a very stiff clay, to as much as 60 psf per foot for sand with silt.

Furthermore, a site that continues uphill behind the house will exert additional force on the excavation or wall equivalent to a couple of extra feet of depth.

### Compacting

In some cases a steep-site foundation will require backfilling one section of the foundation before casting another. If the newer footing is to be placed on a filled area, the soil must be compacted in 6- to 8-inch lifts. A vibrating compactor is sufficient, but don't try to compact soil on a slope. Rather, backfill and compact in level lifts that "terrace" up the slope. Flooding the soil with water is not a successful method for compacting, as it only carries away the fines.

### Two-Level Slabs

A very steep site, sloping more than 8 feet within the width of the house, could result in having a basement wall as much as 12 to 20 feet high. Even when this vertical span is supported at the midpoint by a wood floor, it is not in keeping with normal house construction, because it would require a heavily reinforced concrete or masonry wall and a 20-foot-deep excavation. To prevent cave-ins, the cut may have to slope back as much as 40 feet from the edge of the footing.

To avoid this costly and impractical approach, I usually advise builders to step the basement walls in two sections (see Figure 1). In this way, the lowest part of the house (which often serves in part as a drive-under garage) is about half the size of the first-floor living space above. The upper foundation walls are built after the lower ones are completed and backfilled.

In this type of foundation, the upper wall and footing are reinforced to act as a grade beam–to transfer loads between the uppermost footing (which sits on undisturbed soil) to the pilaster. Note in Figure 1 that the pilaster and upper footing are well below the upper slab. This is to keep the upper footing far enough below grade for frost protection.

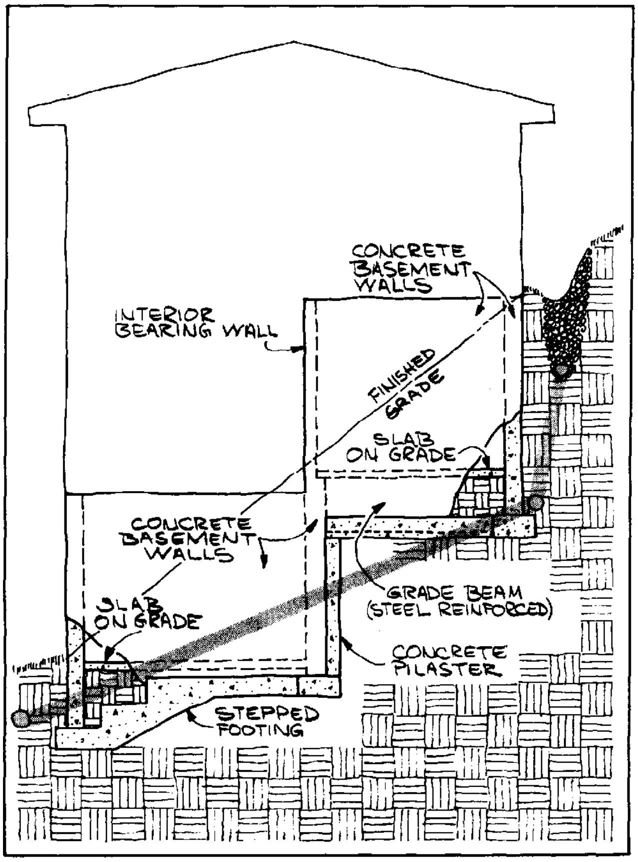



*Figure 1. This hillside house uses slabs at two elevations to eliminate the need for an extra tall foundation wall. The upper wall and footing are reinforced to act as a grade beam. Note the uphill interceptor drain which diverts water to the subdrain system.*

## Step Footings

Rather than use a heavily reinforced grade beam for a stepped foundation, it is often more practical to "step" the footing. Stepping the footing enables you to use unreinforced concrete walls, since the walls do nor have to transfer vertical loads. Stepping keeps the footings at a uniform depth to prevent frost damage. Also, stepping the footing eliminates the risk of undermining the footings at the upper levels due to excavating and backfilling at the lower levels. Figure 2 shows a typical step footing, here used to support a garage foundation.

The bottom of this type of footing steps downward, usually at a proportion of 2 horizontal to 1 vertical— and in section looks like a step. The dimensions are often 2 feet across and 1 foot down or 4 across and 2 down, depending on what forms are available.

## Retaining Walls

All foundation walls that retain soil are technically retaining walls. There are two types of retaining walls—the cantilever wall and the basement wall.

The cantilever has a fixed base, meaning that it has a very large footing and is "moment connected" to the footing. That is, the reinforcing extends from the footing into the retaining wall for a distance such that the reinforcing bars overlap. The wall's stability depends on the moment connection and the size of the footing.

The basement wall, on the other hand, is held in place at the bottom by the soil against the footing, and at the top by the floor system, which will transfer any lateral load to the perpendicular walls. Since this is a vertical simple beam, any necessary reinforcing goes on the inside face of the wall. With the cantilever wall, reinforcing would go on the outside face adjacent to the soil. (The reinforcing goes on the side of the wall loaded in tension.)

The basement-type wall is far less expensive to build because it can be thinner, use less reinforcing, and sirs on smaller footings. However, the floor must be installed or the walls temporarily braced before backfilling.

In some cases, a cantilever wall must be used. One common example is where the owner or architect wants a wood kneewall on the above-grade portion of a basement wall that runs down the slope (see Figure 3). I have observed numerous failures in this type of wall because the joint where the kneewall joins the retaining wall had been pushed inward and the concrete wall had cracked near the footing.

Kneewalls can be used successfully in sites with low soil pressure and where the soil height against the concrete wall (above the slab level) is 2 feet or less. With very steep sites, however, the soil height is usually much greater.

The foundation wall on the lower end of the site may have no soil against the unsupported section of the wall (for example, the high wall in Figure 2). Since this is nor a retaining wall, concrete is unnecessary here, and a wood-frame wall will work. A 4- to 8- foot-long return on each end of the concrete wall is sufficient to transfer any horizontal soil forces back to the ground (Figure 4). In most cases, wood siding will look better here than two stories of concrete or parged block.

## Water

Water, both ground and surface, is probably one of the greatest hazards to steep-site foundations. I have seen a multitude of problems caused by the down leader from the rain gutter depositing water onto the ground or into a so-called "dry well." This invariably leads to a wet slab, cracks in the basement wall, and water penetration into the basement. Also, the higher water content increases the soil pressure against the basement wall.

The water from the down leader must be conducted away from the house, either above or below ground. If you choose a subdrain system, make sure you leave access through a cleanout or the system can become permanently blocked. The down leaders can be drained either by a swale, a small trench, a gravel drain at the surface, or a connection to the subdrain system.

Surface drainage around the basement is another consideration. Generally, sites should be drained away from the construction. With the upward sloping site, however, this is nor possible, so I would recommend installing both a subdrain system around the house and an interceptor trench. This is a ditch dug several feet from the house, with the adjacent land sloping toward the trench and away from the house. The trench is then filled with gravel, a porous pipe is put on the bottom, and soil-stabilizing fabric is laid on top to encourage the growth of grass and avoid the appearance of a row of gravel across the back yard. This way, the runoff can flow downward into the trench, and be conducted away from the house. The perforated pipe would then be connected to a system carrying the water away to free drainage.

Groundwater is yet another problem. Building high on a hillside is no guarantee against groundwater problems, since the water table often follows the slope of the grade. The best answer is, of course, to build the floor above the water table, but this may not be possible if the water table rises substantially during parts of the year.

Whether the site is steep or flat, flooding will occur when the water table is higher than the basement floor. While this is unpleasant, it will nor create additional forces on the wall because the water will fill the basement and surrounding soil simultaneously. Many homeowners have installed sump pumps with backup pumps to keep the water our of their basements. But rather than depending on the one-point drainage of a sump pump, I would suggest a grid of porous pipes, laid beneath the slab. The pipes are then conducted toward a well where the water is ejected outside.

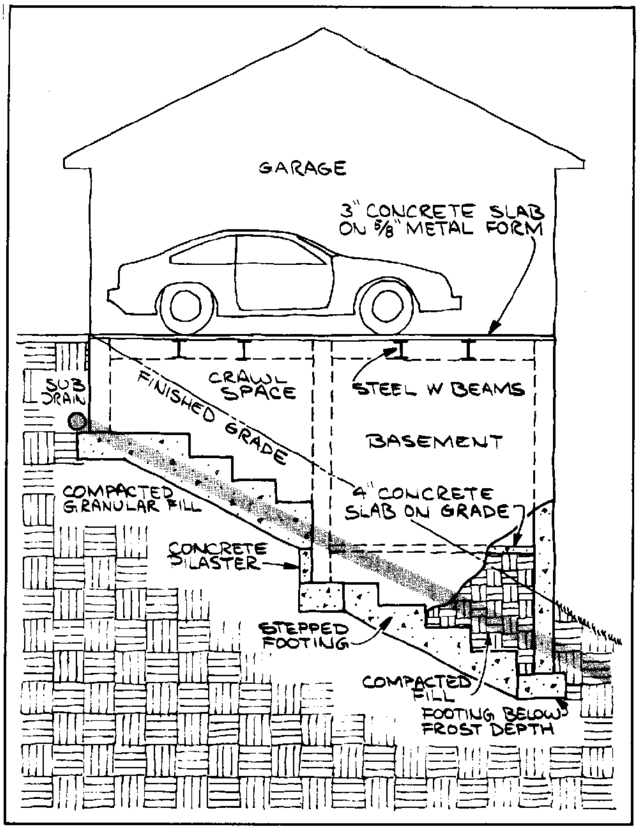



***Figure 2.*** *A typical step footing supports a garage built on a downhill slope. Stepping keeps the footing at a uniform depth for frost protection. Also, it eliminates the risk of undermining the footing during construction.*

## Garage Loading

If the house is built into the slope, parking will be at grade level and support will not be a problem. However, if the site slopes away from the front, it will become necessary to support the car. This cannot be done with a wood frame structure such as plywood over 2x10s. It will require some type of concrete slab, either precast or cast-in-place on steel beams. The issue here is not the overall weight of the car–which is actually within the normal 30 psf of house loading–but that the entire weight of it is concentrated under the four wheels, which may occur anywhere on the floor. I would recommend a cast-in-place concrete slab over a metal deck, which would span between steel beams. Another possible solution is the use of precast planks with a hollow core. Open-web steel joists are still another option but, in addition to their cost, they would require a waiting period for fabrication and shop drawings.

## Sophistication Needed

Regardless of design, you'll need greater technical sophistication to solve the problems of a steep site than on flat land. And both owners and builders must be aware of the potential hazards of inadequate design. Also, problem-site foundations will always cost more than ordinary construction. But by combining conventional materials and techniques with good design practices, you can control the cost without sacrificing construction quality. ■

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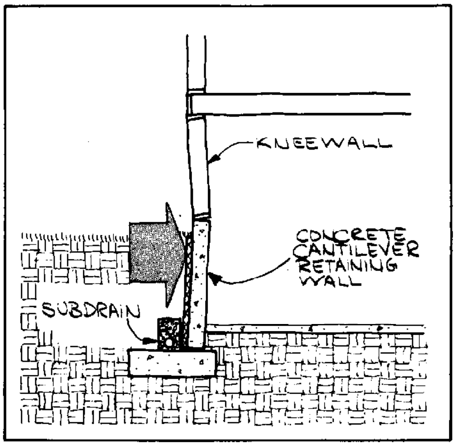


***Figure 3.*** *Some designs call for a wood kneewall up the side of a stepped foundation. With this detail, however, the foundation wall can be pushed in and crack near the footing.*

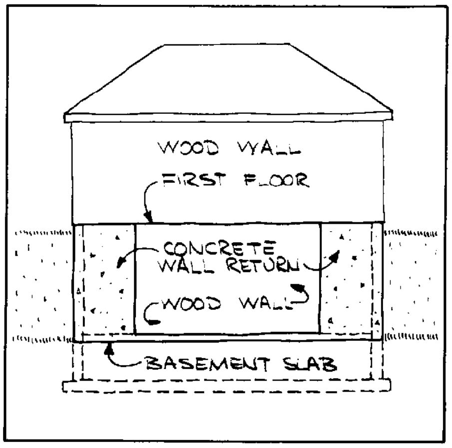


***Figure 4.*** *The downhill side of a sloped foundation need not be concrete since there's little or no unbalanced soil pressure. A wood-framed wall will do the job–with a concrete return at both ends.*