



A Pier and Grade-Beam Foundation

Advice from a contractor on one way to build on a steep slope

by Michael Spexarth

As good home sites get harder to find, many builders are looking at hillside lots that used to be considered unbuildable. A builder who can cope with the special foundations required on steep sites can often buy a lot for a modest sum, and build a house that enjoys an attractive view of the scenery below.

Here in the San Francisco Bay area, chances are good that you'll find a pier and grade-beam foundation under just about every new hillside home. This type of foundation links a poured concrete perimeter footing to the ground with a matrix of grade beams and concrete pilings, some up to 20 ft. deep. The resulting grid grips the hillside like the roots of a giant tree (see pp. 31-33). Slopes in excess of 45° can be built on with this kind of foundation. And in areas where there are landslides, expansive soils or earthquakes, a pier and grade-beam foundation may be required by local building codes.

As a rule pier and grade-beam foundations need more reinforcing steel than conventional foundations, and require special concrete mixes. On the other hand, they usually call for less formwork than perimeter foundations do. What's more, the footings for grade-beam foundations don't have to be level.

Soil survey—A soil engineer's report is usually required by local codes, and even if it isn't, it's smart to get one. Because the tendency on steep sites is to overbuild, the survey's recommendations may reduce the number and size of piers, which designers or engineers with less knowledge of geology will spec to err on the side of caution. This kind of needless overbuilding wastes money.

To make the survey, the soil engineer will make test drillings or trenches at various spots around the site with a drill rig that typically bores a 6-in. dia. hole. Or he will bring in a backhoe. At various depths, core samples are taken with a cylinder that is lowered into the test hole. Although they will vary from site to site, these holes are usually 20 ft. deep or less because that's the limit of most drilling rigs used to bore the finished holes. The engi-

neer will take the soil samples back to the lab and analyze them to determine their bearing and expansion characteristics.

These tests, taken together, give a picture of the soil types and conditions at various depths, and of the natural water courses. Armed with this data, the soil engineer makes recommendations about the number and the diameter of the piers needed, and their depth. He specifies the steel-reinforcing requirements and the minimum distance between the piers. In northern California, the typical soil survey costs between \$1,000 and \$1,500.

Site preparation—The first order of business is to get rid of unwanted plants, loose topsoil, logs and other debris that isn't considered a permanent part of the landscape. Once the lot is cleared, mark stumps, rocks and areas of soft, wet soil with stakes and flagging. The safety of your drill operator could depend on his knowing what's where.

Upslope lots are usually more difficult to deal with than downslope lots. Here's the rule of thumb around here. A foundation on a downslope lot will probably cost twice as much as a foundation on a level site; a foundation on an upslope lot will be three times as expensive. In addition to moving the weight of the entire house uphill, the builder has to deal with the problem of hauling off tons of dirt.

Most soils are compacted in nature, and when drilled into or excavated, they can expand to two or three times their undisturbed volume. A 16-in. dia. by 18-ft. deep pier hole will contain about 1 cu. yd. of compacted soil, which will become as many as 3 cu. yd. of loose soil. So if 15 pier holes are drilled, you might have 45 cu. yd. of loose soil covering the site, or a volume 20 ft. by 30 ft. by 2 ft. deep. This soil can change the contour lines in the site plan, the elevation of the house, the loading on the foundation, and the drainage of the hill. So you have to move it out of there.

In the Bay area, some building departments allow loose soil to be evenly distributed up to 3 ft. deep if the slope is less than 18°. Such soil-dispersal zones must be away from natural drainage channels. On steeper slopes, the loose soil has to be removed or buttressed with a retaining wall to keep it from creeping downhill. Other building departments ask the soil engineer to recommend soil removal or dispersal, then the county inspectors check the project to see if they agree. Each jurisdic-

tion has its own policies governing drilling spoils. You should find out what they are to avoid trouble later.

Most builders stockpile the soil during construction, and then use it for landscaping once the building is finished. If the soil is unusable, or there's just too much of it, it has to be hauled off. We usually rent a dump truck and a tractor with a front-end loader to move the stuff, and take it to the nearest fill site.

Layout—The standard batter board used to locate the corners of perimeter foundations isn't the best solution for layout on slopes. Batter boards don't work well because most pier holes are drilled by a tractor-mounted auger, and as the operator maneuvers the rig around the site, chances are good that the batter boards and some of the survey stakes will be crunched into little splinters. In addition, 12-in. survey pins marking the exact location of piers can shift around in loose topsoils. A D6 Cat weighing around 10 tons may push loose topsoil downhill 1 ft. to 3 ft. as it lumbers around the site. So although the pins may appear to be in the correct relationship to one another, they might have moved downhill with the topsoil. This can cause a lot of problems when you start building your forms.

In order to ensure the correct siting of the house, and to guarantee exact layout points for drilling each pier, I arrange to get my surveyor on the site as the holes are being drilled. The surveyor centers the transit over a survey hub at a fixed elevation away from the drilling area, and then uses a chain (surveyor's tape measure) to locate the corners of the foundation and piers as calculated degree angles are turned. This ensures that no matter what soil movement has affected the preliminary stake positions, each pier hole is located precisely, right at the time it's drilled. The extra cost involved in having the surveyor on site is usually negligible compared to the additional labor and material necessary to do the whole job over again if your pier holes are drilled in the wrong places. If you can't get your surveyor on the site during drilling, the best alternative is to place reference points outside the drilling area to double-check stake location as the pier holes are being bored.

Drill rigs—There are two basic types of drill rigs: tractor or crawler mounted, and truck-mounted. Within these two categories you'll

Dirt flies as a tractor-mounted auger pulls soil from a 20-ft. deep pier hole. Rigs like this can work on slopes as steep as 45° or a little more. The ever-present helper with a shovel positions the auger, plumbs the drill shaft and directs dirt away from the hole.



Rebar for grade-beam and pier cages is assembled on site with jigs nailed to the top of sawhorses. The slots in the jigs position the #4 steel as #3 rebar stirrups are tied in place. Finished grade-beam cages await installation atop the woodpile. A rebar offcut used as a stake holds the woodpile in place.

find rigs that are as different as the people who operate them. The truck-mounted rigs have an auger attached to a boom that can reach several drill targets from one setup point. Such trucks do less damage to a site than a tractor, but they can't negotiate slopes greater than about 30°.

Tractor-mounted augers can drill in terrain that is inaccessible to trucks, and they can work on slopes up to 45° or slightly more. Sometimes an operator will anchor his tractor's winch cable to a stout tree or to a dead-man driven into the ground uphill. Some operators carry a power pole on their cat. They auger a hole at the top of the slope for the pole and hook the cable to it. This lets them hang on the side of a steep slope as the holes are drilled. It's a chilling sight.

Drill operators generally charge by the hour, by the footage (the cumulative depths of the holes they drill) or by the job. They base their fees on the capabilities of their equipment, on the difficulty of the job and on the kind of soil they're working in. The rig that's pictured in this article cost \$130 per hour, and it took 12 hours to drill 16 pier holes. And with a crawler-type rig, there is an additional delivery charge (often called travel time) tacked onto the hourly rate—\$150 for this job. In rocky locations, you can expect a surcharge that will cover the cost of broken equipment, such as auger teeth.

Although these rigs can drill holes up to 20 ft. deep, soil conditions can change every few feet. One hole can be 6 ft. deep and hit rock, and 8 ft. away the next hole might be 18 ft. deep before the same layer of rock is engaged. The variables are surprising, so un-

less you're good at poker (or bridge), do this type of bidding liberally.

During drilling, soil lifted out by the auger is deflected away from the hole by a helper using a shovel (photo, p. 34). The helper will also need a hose to water down the auger bit. Water lubricates the tugging action, reducing the time needed to bore the holes, and lengthens the life of the equipment.

The loose dirt is left at the bottom of the hole because it's too far down to clean it out. Because pier and grade-beam foundations work by friction rather than direct bearing, this loose soil isn't usually a problem. But several years of drought can cause the soil around the piers to shrink and reduce the friction that holds the house on the hill. Enough shrinkage, and the house begins to settle.

You can limit the possibility of soil shrinkage by pouring a few gallons of water and a third to a half-bag of portland cement into each hole after the final depth has been reached and the auger has been removed. Then have the operator re-insert the auger for a minute's worth of mixing. The auger works like a giant milkshake machine to blend cement, water and tailings. When it's lifted out again, the mix should be thin enough to ooze off the drill bit. Once it hardens, this slurry forms a pad that will take direct bearing, and so lessen the chances for foundation settlement during dry years.

Once the holes are drilled, we cover them with plywood to keep out loose topsoil and debris. If there's even a remote chance that small children might wander onto the site, we stake the plywood to the ground and cover it with loose topsoil to make the area uninter-

esting. We also notify the neighbors that there are deep holes covered with plywood on a lot nearby, and we post the area.

Concrete and steel—A pier and grade-beam foundation has a lot of steel in it, and an equally large volume of concrete—100 cu. yd. is not uncommon. These foundations are a lot like icebergs, with their bulk concealed below the surface. With this much steelwork, the builder who sets up an efficient way to fabricate the beam and pier cages can save money.

On a recent job we assembled #4 rebar cages on sawhorses using #3 rebar stirrups and spirals. We easily bent the #3 steel with a rebar bender, and wired the straight pieces in place with standard foundation tie wire (photo above). Some foundations call for heavier steel, and anything over #4 (½-in. dia.) is difficult to bend. If your specs show a lot of #5s, #6s, #7s, consider having the stirrups and spirals fabricated at a metal shop and then delivered to your site for cage assembly.

The foundation can be monolithic, or it can happen in two pours. This latter way produces a cold joint between piers and grade beams. For this job we poured the piers first, and let the cages run long for ties to the grade beams. We suspended each pier cage in its hole with a rebar offcut placed under a stirrup, as shown in the top left photo on the facing page. After the piers were poured, we bent the ends over and tied them into the beam cages (photo facing page, top right).

Forms—When we build our forms depends on the configuration of the rebar. If the grade-beam steel is a series of interconnected cages,

we tie them together and then build the forms around them. This allows for adjustment if any piers are out of alignment. The outside of the forms defines the shape of the house, and registers the placement of the mudsills.

If unconnected individual bars are used for the grade-beam steel, it's easier to build the forms first and then place the rebar. Since the forms are built according to the contours of the site, nothing has to be level. We pre-drill the mudsills, insert the foundation bolts and then place them in the wet concrete (photo bottom right). Leveling the house occurs when the foundation walls, sometimes called pony walls, are built.

Pumped concrete—The standard pumping mix in this area contains $\frac{3}{8}$ -in. pea gravel in a six-sack mix. This aggregate size allows you to use the lower-cost grout pumps, which have a 2 or 3-in. dia. hose. These pumps are pulled behind a pickup, and can pump the concrete 150 ft. up a 45° slope. The six-sack mix has one bag more portland cement than the usual mix. The richer mix is needed to achieve a higher compression rating than you get with the smaller-size aggregate.

You should have water available for lubricating the pump hose, washing loose soil out of the forms and, if pouring the beams separately from the piers, for removing any dirt that may have accumulated on top of them. For cold-joint connections, an epoxy bonder applied to the top of the piers just before the grade beams are poured will help ensure a good bond between the two pours.

Pumpers usually know about how much water they want in the mix, and they will check the mud in the transit mixer for water content. A stiffer mix can clog a dirty hose, and it makes the pump work harder. Since adding more water will lower the psi rating of the concrete, try to hire a pumper who keeps his equipment in good condition. Tell the batch-plant dispatcher you are using a pumper on a steep slope. Adding a water-reducing agent will keep the mix soupy enough to pump and still achieve the required psi compression rating when it cures. Around here this admixture costs only about \$2 per cu. yd., and it adds about 1½ in. of slump to a load.

But I still prefer a stiffer mix because it won't run downhill as much as a wet batch. We make an initial pass around the forms, filling them half full. With a stiff mix, the concrete is able to carry some of its own weight by the time we pour in the rest.

If you happen to hear that glorious sound of bursting forms and splitting stakes, halt the pumping immediately. If you wait for 30 minutes to an hour, the mix should set up enough to allow you to continue, despite a weak spot in the formwork. In the meantime, fill other areas of the foundation. Even in mild weather, stripping forms the next day won't keep your engineer happy, but it allows you to get your form lumber back in usable shape. □

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A pier cage hangs on a rebar beam (above left) as concrete is pumped into the hole. The protruding bars will be bent over to tie into the grade-beam steel. Once the concrete piers have set up, the pier-cage steel is bent over to tie into the grade-beam cages, as shown at top right. Because there are so many splices involved in the steelwork, Spexarth first installs the cages, then constructs the forms around them. Redwood mudsills are cut to length, and placed near the appropriate footing.



As the wet concrete for the grade beam is screeded flush with the top of the form, the sills are embedded in the wet concrete and checked for side-to-side level. The J-bolt protruding from the sill will be worked down into the concrete, and the nut will be tightened after the beam cures.