Foundations on Hillside Sites

An engineer tells about pier and grade-beam foundations

by Ronald J. Barr

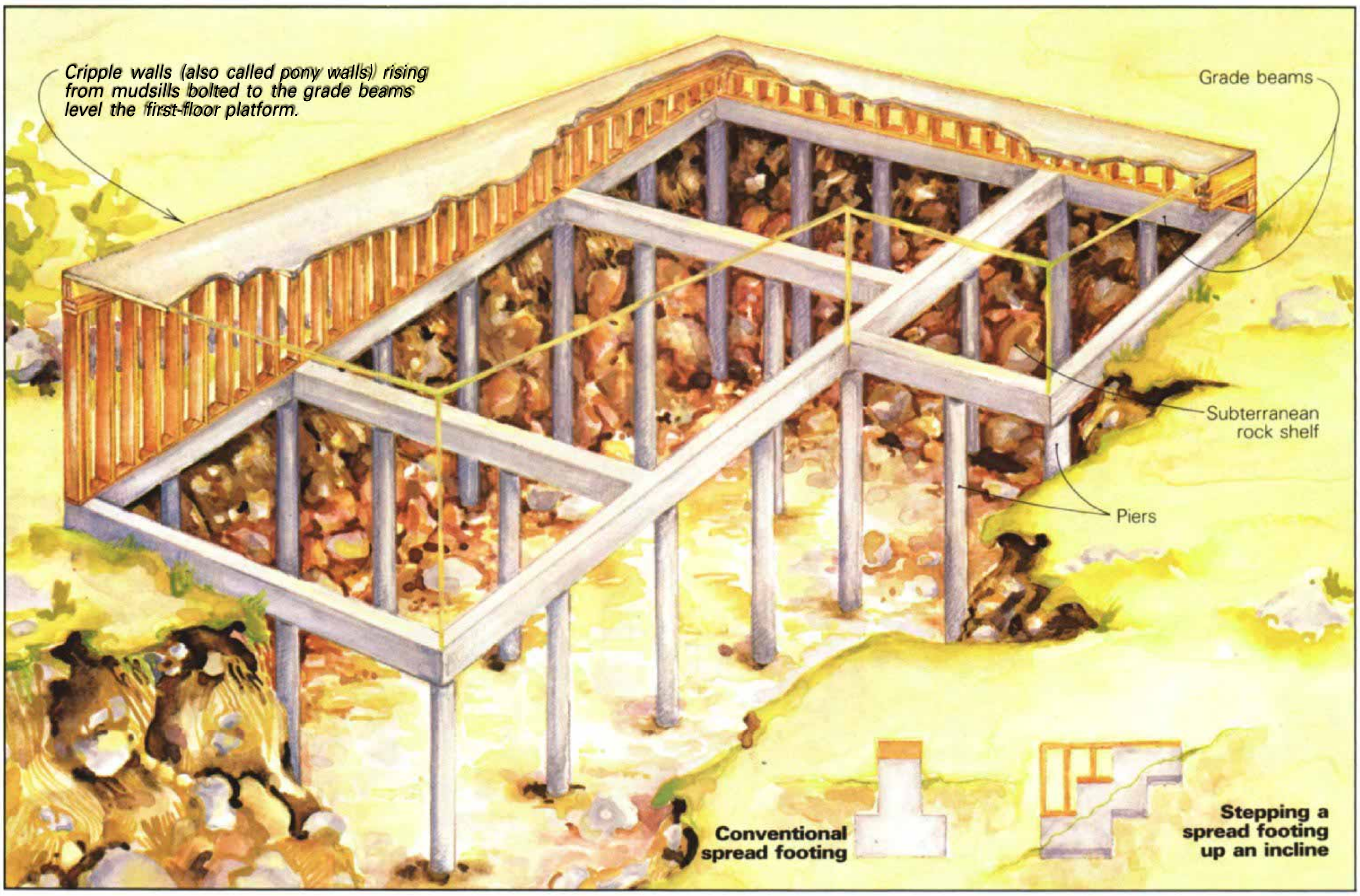
Most houses built on conventional sites sit atop a spread-footing foundation. It has a T-shaped cross section (small drawing, below center), and supports the house by transferring its own weight and the loading from above directly to the ground below. Spread footings can be used on sloping sites by stepping them up the hill (small drawing, below right), but this usually requires complicated formwork and expensive excavation. For slopes greater than 25°, the structurally superior pier and grade-beam foundation (large drawing, below) may be less costly. Apart from making steep sites buildable, pier and grade-beam foundations make it possible to build on level sites where soils are so expansive that they could crack spread footings like breadsticks as the earth heaves and subsides.

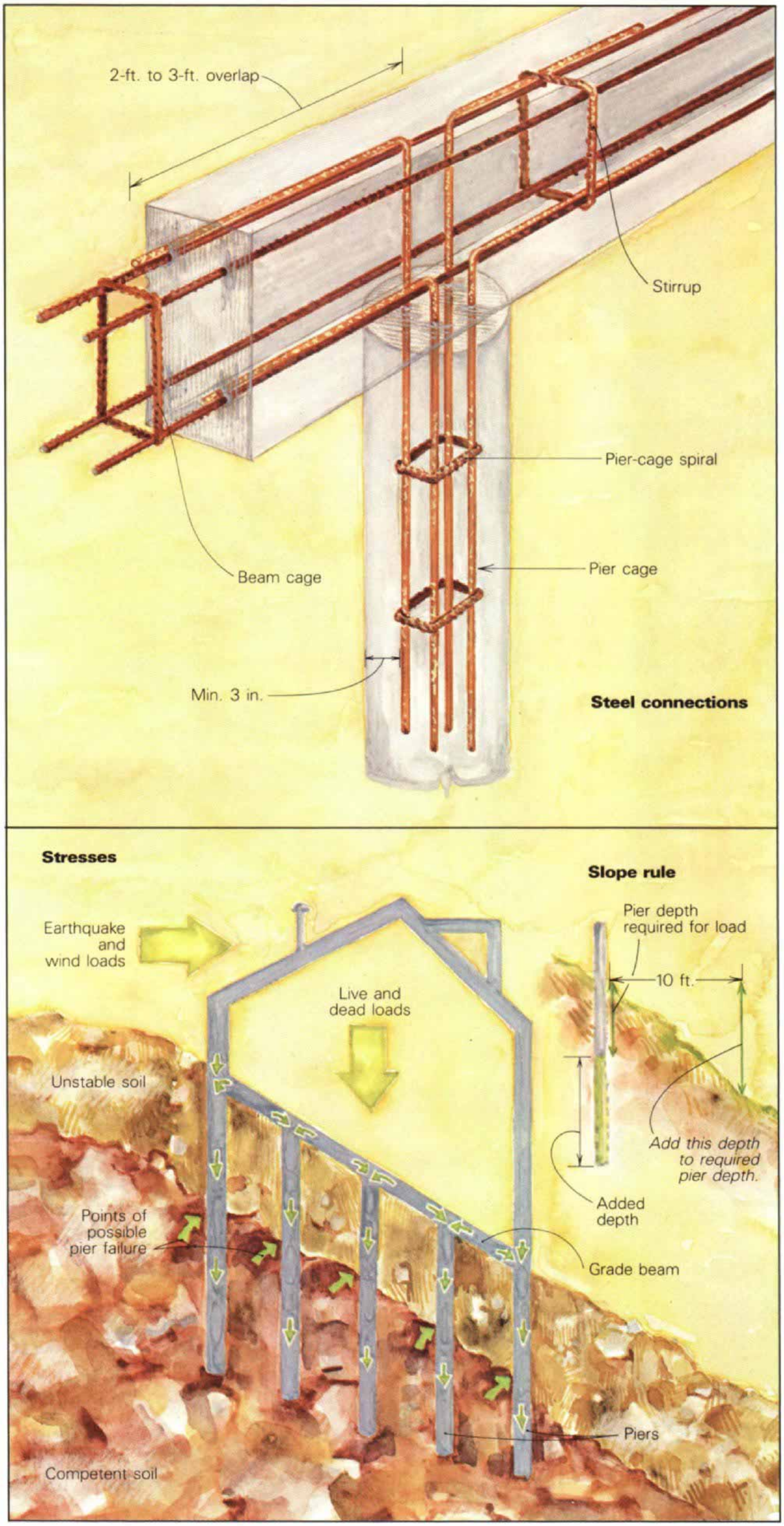
How they work—The pier and grade-beam foundation supports a structure in one of two ways. First, the piers can bear directly on rock or soil that has been found to be competent. This means it's stable enough to act as a bearing surface for the base of the pier. Second, the piers rely on friction for support. This is what sets pier and grade-beam foundations apart from other systems. The sides of the concrete piers develop tremendous friction against the irregular walls of their holes. This resistance is enough to hold up a building. A structural engineer can look at the soil report for a given site, study the friction-bearing characteristics of the earth and then specify the number, length, diameter and spacing of the piers that will be necessary to carry the proposed structure.

The rigs used to drill pier holes for residential foundations have to be able to bore holes 20 ft. deep or more. Foundations have to extend through unstable surface soil, such as uncompacted fill, topsoil with low bearing values and layers of slide-prone earth. Anchored in stable subterranean strata of earth or rock, deep piers don't depend on unstable surface soil for support.

The slope of the lot and the quality of the surface soil influence the size and placement

A pier and grade-beam foundation. **Deep piers extend through layers of loose topsoil to lock into the stable soil below, which can support the weight of a house. The grade beams follow the irregular contour of the site, and transfer the building's loads to the piers.**





of reinforcing steel in each pier (drawing, left). The steeper the lot and the more suspect the soil's stability, the bigger the steel. This is because the pier doesn't just transfer the compression loads from the house to the ground. It also resists the lateral loads induced by winds, earthquakes or by the movement of surface soils, which result in a kind of cantilever beam-action on the piers, as depicted in the drawing below left. They have to be strong enough to resist these forces—pier cages made from 1-in. rebar are not uncommon in extreme cases.

Grade beams—As the name implies, a grade beam is a concrete beam that conforms to the contour of the ground at grade level. Grade beams require at least two lengths of rebar, one at the top and one at the bottom. Foundation plans often call for two lengths at the top and two at the bottom, tied into cages with rectangular supports called stirrups. The bars inside the beams work like the chords in a truss, spreading the tension and compression forces induced by the live and dead loads of the structure above.

The sectional size of the grade beam depends on the load placed on it, and on the spacing of the piers. Pier spacing is governed by the allowable end-bearing value of the piers, or by the allowable skin friction generated by the pier walls and the soil under the site. Pier depth ranges from 5 ft. to 20 ft.; pier spacing, from 5 ft. to 12 ft. o.c. Pier diameters are normally 10 in. to 12 in., and can go up to 30 in. Beam sections start at about 6 in. by 12 in. and go up.

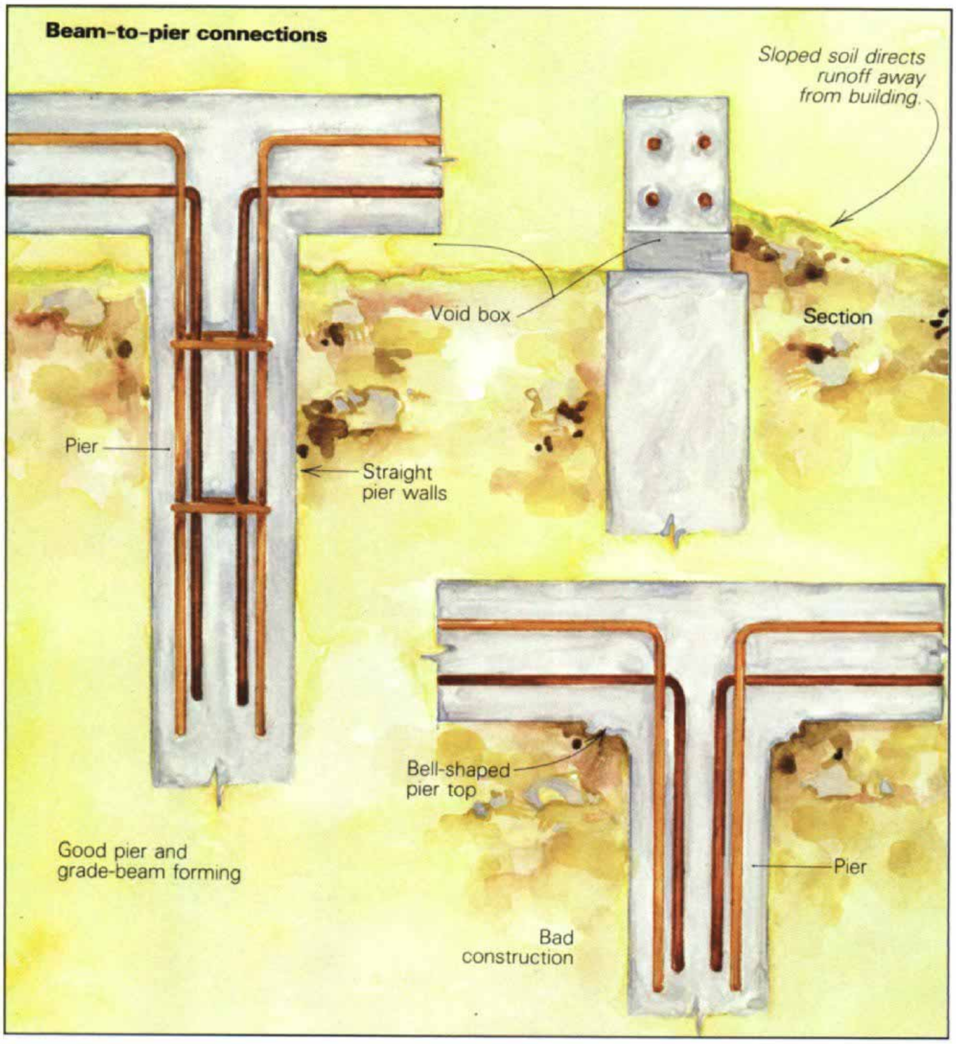
Because of the number of variables involved in designing a pier and grade-beam foundation, the engineering is best left to a professional. It's not happenstance that there are lots of lawsuits over foundation failures—many of them on slopes.

What the engineer needs—An engineer designing a pier and grade-beam foundation has to know what lies beneath the surface of the site. A soils engineer's report is usually required for this information, (see p. 35). Sometimes the city or county building department will have records of soil characteristics in your area. The engineer also needs a copy of your house plans to calculate the loading on the foundation. If you can, tell the engineer what pier size your excavator can drill. If you're planning on making the steel cages yourself, ask your engineer about rebar diameter requirements. Although he may specify #5 or #6 rebar, which is impossible to bend in the field, it could be that more #4s (½-in. rebar) would do the job just as well.

Make sure you find out the spacing and size

Engineering considerations. **The steel embedded in each pier must resist the lateral loads from wind or earthquakes, which are transferred to the piers at the junction of the unstable and competent soils. If piers are embedded in a slope, the amount of slope rise in a 10-ft. run must be added to the pier depth required for load.**

Pier and grade-beam in expansive soils. **A well-engineered system has a 2-in. gap between the grade beam and the soil, to allow for expansion. The pier should be straight, not bell-shaped at the top, so loads are transferred down to the stable soil.**



of the anchor bolts your foundation will need for fastening sills to the grade beams. For some downhill slopes, the cripple walls (drawing, p. 31) will need additional blocking, and anchor bolts placed 2 ft. o.c.

Piers on a slope must be longer to compensate for the lack of soil on the downhill side (inset drawing, facing page, bottom). Figure the additional length as follows: Tie one end of a 10-ft. long string to the stake marking the pier location, and pull it taut downhill and hold it level. The distance from the end of the string to the ground directly below has to be added to the pier hole to compensate for its location on a slope.

Void boxes—Ask your engineer whether you can cast (pour) the grade beams directly on the soil, or whether they should have void boxes under them. A void box (drawing, right) is a gap, usually about 2 in., between a grade beam and expansive soils. Some builders put a 2-in. thick piece of Styrofoam at the bottom of the grade-beam forms before the pour. Once the forms have been stripped, they pour a solvent along the base of the grade beam to dissolve the Styrofoam. Another method is to fold up cardboard boxes until you've got a stack 2 in. thick, and then lay them at the bottom of the forms. You don't have to remove them—they'll rot away.

When I worked as a building inspector, I saw what can happen to a house when void boxes aren't included in grade-beam pours over expansive soils. A couple of home owners asked me to find out why their foundation had settled in the center of the house. There was a large fireplace there, and they thought it was the culprit. But it wasn't. The fireplace showed no signs of movement. However, outside the perimeter grade-beam foundation, recent rains had caused the clay to expand, raising the foundation (and the exterior walls) as much as 2 in. in places. The center of the house had stayed put, and everything else had risen around it. None of the doors or windows worked, and every wall in the house was cracked. Voids under the grade beams would have prevented all this.

Problems—Once the foundation design has been determined and your driller is on site, it's almost inevitable that something unexpected will happen. For instance, your excavator may not be able to drill to the depth specified on the plans. Sometimes you can get away with this; other times you have to provide for another pier nearby. If you're drilling friction-bearing piers, you may have to change their diameter and spacing, or change their end-bearing condition. Check with your engineer for the correct course of action.

Drill alignment sometimes slips during drilling, and the auger can break into an adjacent pier hole. If this happens, check with your structural engineer. The remedy will depend on the load-bearing requirements at that particular part of the foundation.

Watch the soil as it's being removed from the pier holes. Its appearance should change in the upper half of the hole, as the drill leaves the topsoil layer and passes into the more stable soil. If you notice an abrupt change in the color or texture of the soil at the bottom of the hole, get in touch with your soils engineer right away, because a change in soil type may mean you'll need to drill deeper piers to make sure you're into solid earth. Shallow piers are the cause of most pier and grade-beam failures, so it's best to err on the side of caution and drill those holes deep.

A little while ago I drew up some plans for remedial foundation work for a house that was suffering from short piers. Actually, some of the piers were long enough to extend into solid material, and this uphill portion of the house hadn't moved. But the downhill half rested on shallow piers that weren't engaged with the competent soil layer. The awesome power of the surface layers moving downhill had pulled the house's grade beams apart and stretched their reinforcing rods like taffy. Above these cracks in the beams, the house was slowly being torn in half. Just getting a drill rig to the site required dismantling part of the house, and the necessary foundation repairs ended up costing $60,000.

After the drilling—Grade beams should be centered over the piers. If one *is* out of alignment by more than a few inches, the eccentric load placed on the pier could eventually crack it in half. Rebar splices should overlap by 3 ft. And make sure that the tops of the pier holes haven't been widened to create a bell shape (drawing, above). Such a bell can be a bearing surface for expansive soils, and can cause uplift problems during wet weather.

A pier and grade-beam foundation usually doesn't need a special drainage system, but it's important to direct runoff away from the building. Banking the soil a few inches up the exterior side of the grade beam is generally all that's needed, and won't appreciably intrude into the void under the beam (drawing, top). The important thing is to make sure that running water doesn't wash away the soil around the piers. This erosion might not be critical if the piers are end-bearing, but if they are friction piers, the washing action could severely limit their load-carrying capabilities. □

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