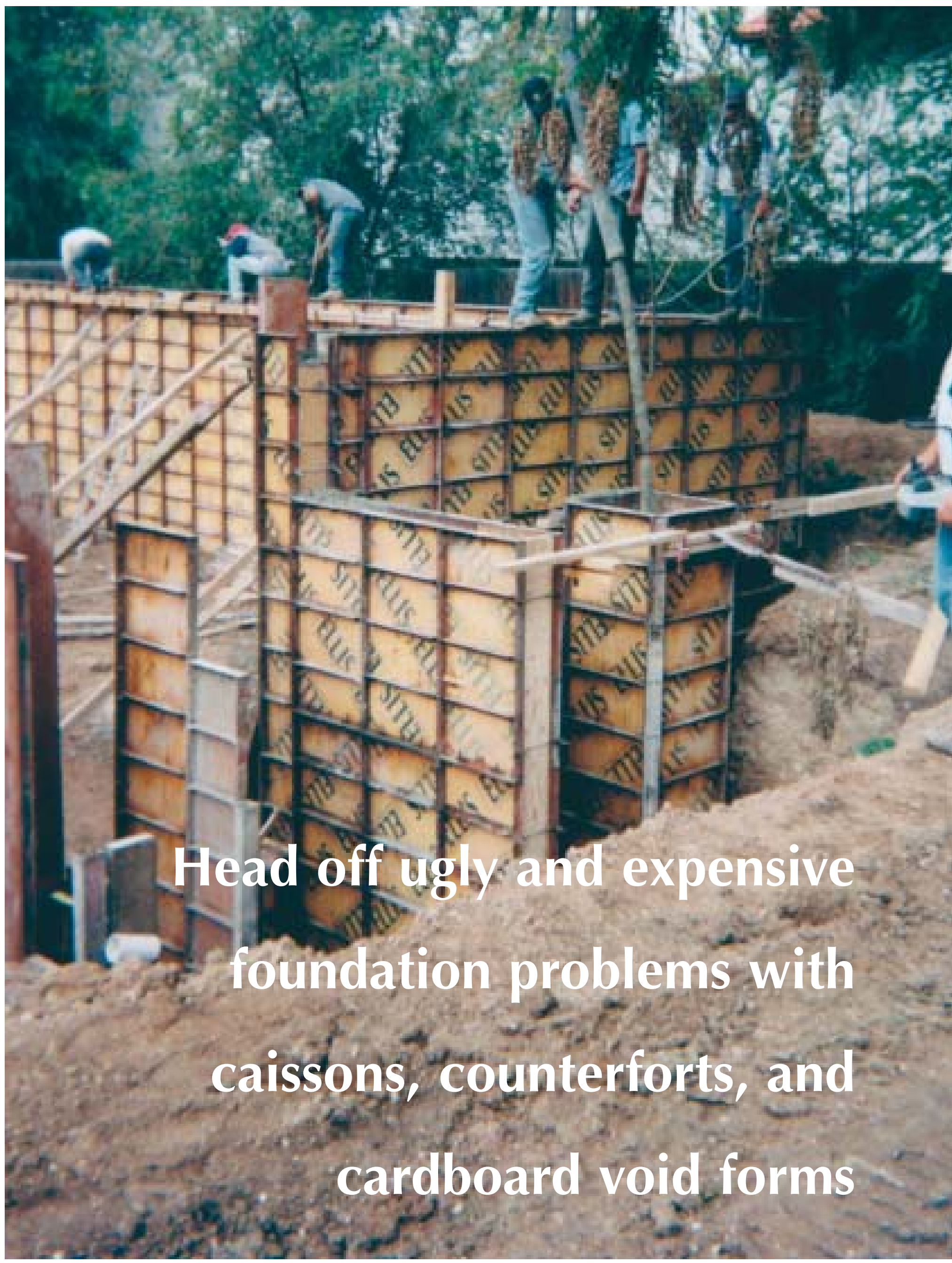
TROUBLE-FREE Foundations for Expansive Soils

I'm a general contractor in the Front Range area of Colorado, where many building lots have expansive clay soils beneath the surface.

by David McMahon



Head off ugly and expensive foundation problems with caissons, counterforts, and cardboard void forms

Improperly designed or carelessly constructed foundations can fail disastrously in this environment. Isolated column pads tend to heave, while footings, walls, and slabs crack and break, leading to out-of-level floors, racked doors and windows, and cracking of finished surfaces (see Figure 1, next page). Fortunately, these sorts of problems are almost completely preventable, and while prevention can add several thousand dollars to the cost of a foundation, it's a lot cheaper than replacing a failed foundation later on.

What Are Expansive Soils?

In general, an expansive soil is any soil or rock material that has the potential to shrink or swell under changing moisture conditions. The specific characteristics of problem soils, however, vary from region to region.

In the north-central and Rocky Mountain areas of North America, including North and South Dakota, Montana, Wyoming, and our part of Colorado, the expansive soils problems are primarily related to the presence of clays and weathered shales. In this area, construction-related changes in local drainage patterns lead to increased soil moisture and consequent

Figure 1. Expansive soils can exert tremendous pressure on slabs, piers, and foundation walls. Heaving backfill was responsible for the inch-wide crack in this garage slab.

Soil-Test Basics

An experienced observer can often recognize surface features that suggest the presence of expansive soil, but unless you have geologic x-ray vision, you can't tell what you'll find below grade on an undeveloped site.

As a result, building departments in expansive-soil areas usually require a soil test — sometimes called a Subsurface Exploration Report — for a planned building site.

The architect or structural engineer who designs the structure will use the report's findings to draw up plans for a suitable foundation. Since our company specializes in custom homes, the design of the structural foundation system is a collaborative effort between the geotechnical engineer, structural engineer, and architect.

Most soils reports begin with a summary section that briefly describes the site conditions and the types of soils found and makes a general recommendation for a suitable type of foundation. The report's boring log will classify soils according to the Unified Soil Classification System (USCS) and the American Society of Testing Materials (ASTM) designations. In general, those soil classifications that contain the symbol CL (lean clay), CH (fat clay), or SC (clayey sand) indicate the presence of materials that have expansive properties.

In many states, including Colorado, purchasing a lot in a developed subdivision entitles the buyer to a copy of the soils report drawn up for the original subdivider or developer. Savvy builders often make their lot purchases conditional on their approval of the soils report, thus ensuring that they are not buying into expensive foundation problems.

If your building site is undeveloped, you will need to commission your own report. If recent construction activity has taken place in the area, go to the building department that permitted the job and ask to review the public file on the project. This will provide the name of the geotechnical firm or engineer that recently completed an investigation in the area. They may be willing to discount their fee because they've already done the necessary background research.

—D.M.

swelling problems. In eastern Oklahoma, Texas, Florida and the Gulf states, and the Great Lakes area, on the other hand, the problems include both shrinking and swelling, mostly as a result of seasonal fluctuations in soil moisture. Southern California has an abundance of alluvial and colluvial soils, which are peculiar to arid regions. When exposed to postconstruction moisture, often in the form of landscape irrigation, they're subject to swelling and consolidation problems.

Reinforced Slabs vs. Pier-and-Grade Beams

There are two basic strategies for building on expansive soils: Design a foundation system that is strong and rigid enough to withstand the anticipated soil movement, or isolate the structure from the expansive soils environment.

The first approach usually involves a heavily reinforced slab-on-grade stiffened by a grid of underlying crossbeams. The slab can be conventionally reinforced or post-tensioned with steel-cable tendons, which are stressed after the slab has begun to cure. If it's properly designed, the resulting monolithic slab will resist the upward forces of expansive soil without cracking. Stiffened slabs are excellent foundation systems in areas such as the southern states and California where the depths of expansive soils make pier construction costs prohibitive or where basements are not used.

Under the isolation approach, straight-shaft drilled piers — also known as caissons — extend downward vertically through problem soils to bear directly on bedrock or solid, nonexpansive soils below. The heavily reinforced concrete foundation walls — actually very deep grade beams — are supported by the drilled piers (Figure 2, next page). Expansion spaces just beneath the grade beams accommodate some expansion of the adjacent nonbearing soil. This is the approach we prefer, because it provides for the basements that home buyers in our area demand.

Pier-and-Grade-Beam Foundation

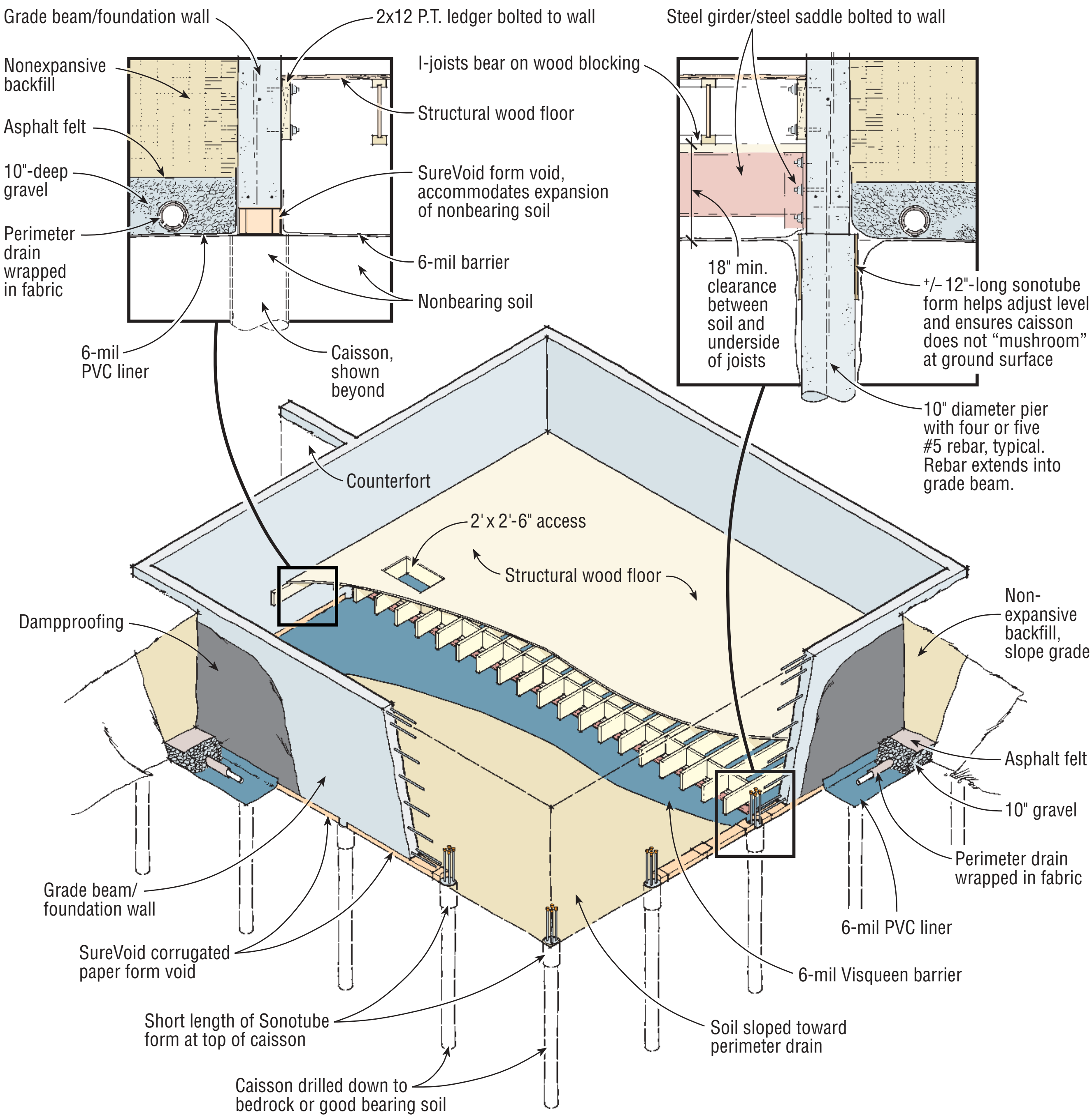


Figure 2. Unlike a conventional poured foundation and continuous strip footing, the heavily reinforced foundation walls of a pier-and-grade-beam foundation are isolated from the underlying soil except where they bear on the caissons, which extend to bedrock or competent bearing soil. Cardboard void forms beneath the nonbearing portions of the walls provide temporary support during the concrete pour but later soften with exposure to soil moisture, creating a space into which the soil can expand without causing damage.

Figure 3. Where caisson boreholes extend below the water table, a temporary steel casing is inserted as the holes are bored. The casing is withdrawn as concrete is pumped into the borings.

Figure 4. The bases of the wall forms rest atop 2x4s nailed to 2x4 stakes driven into the soil at approximately 2-foot intervals. At right, one form has been erected and braced, and the rebar has been wired in place. After cardboard void forms have been placed at the bottom of the wall, the second form will be erected. Below, void forms and rebar are test-fitted before the forms are erected.

Excavating and Pouring Caissons

Because basements in our area are often used as living space, there's a trend toward a full 8 feet of headroom below boxed ductwork and beams. If a structural floor — a suspended wood floor system often used as an alternative to a basement slab — is to be installed, it's become common practice to have 12-foot basement foundation walls to accommodate the depth of the joists and the required clearance to the soil below. All this means that excavations are getting deeper and deeper.

Initial excavation. After staking out the excavation, we use a large track excavator and a wheeled front loader to dig to the prescribed depth. In most cases, the excavated soil is too expansive to use as backfill, so it must be hauled away. On more constricted sites, this has to be done promptly to prevent the excavated material from interfering with the caisson drilling rigs that immediately follow.

Boring and pouring. A typical 3,000-square-foot single-family house will have 20 to 25 caissons. To guarantee an accurate layout and avoid possible setback encroachment problems, we always have a surveyor stake the center point of each caisson in the grid and set a "bottom of wall" elevation stake, which we later use as a benchmark while pouring the caissons.

In our area, caisson construction is subbed out to specialty contractors who use small, highly maneuverable boring rigs operated by crews that aren't afraid to wallow in the muck (Figure 3). The company we use ordinarily sends two crews with boring rigs, which speeds the job and provides backup in case one drill rig breaks down. It's usually up to the foundation contractor to coordinate the drill rig, concrete pump, and ready-mix delivery schedules. The general contractor is responsible for having the soils engineer or technician on site during the drilling process to verify that the required boring depth has been reached.

When the holes are ready, the drill rig is set up to lower the assembled wire cages or loose steel bars that will reinforce the caissons. A standard 10-inch pier normally uses four or five #5 deformed strands of rebar, which protrude above the caisson top for a specified distance to provide a solid connection to the grade-beam steel.

Once the steel has been lowered, we usually friction-fit a short piece of Sonotube form into the mouth of each borehole. This makes it easy to adjust the level to match the "bottom of wall" stake by sliding the tubes slightly up or down. Equally important, it ensures that the caisson will have smooth, vertical sides all the way to the top, without any "mushrooming" at the ground surface. If uncorrected, mushroomed caissons can cause trouble during a future soil-swelling cycle by providing a lip for the soil to push against.

In our area, most caissons are 18 to 25 feet deep. Concrete falling that distance will become segregated and contaminated with dirt on the way down, so a pump setup is the only way to go.

The pour proceeds with the pump hose being inserted into the boring and filling the hole from the bottom up.

Forming Foundation Walls

We usually start placing the forms for the foundation walls the day after the caissons are poured.

There's no continuous strip footing to support the bottoms of the forms, so we provide a solid, level base by driving a double line of short wooden stakes into the soil between caissons and nailing 2x4s to the exposed tops of the stakes (Figure 4, previous page). We erect and brace one side of the form on top of the prepared base, installing snap ties as we go. Beam pockets, windows, and doors are blocked out, and steel reinforcement is tied according to the plans. The amount of steel required will vary with the height of the wall, the imposed load, and whether it has to retain surrounding soils. Where specified by the engineer, short wall buttresses called counterforts are used to strengthen long, straight sections of wall (Figure 5).

Void forms. Next, we place SureVoid corrugated paper void material at the

Figure 5. Large basement windows provide light and air and satisfy egress requirements but reduce the foundation's ability to resist lateral soil pressure. Reinforcing buttresses, or counterforts, are used where needed to provide added strength.

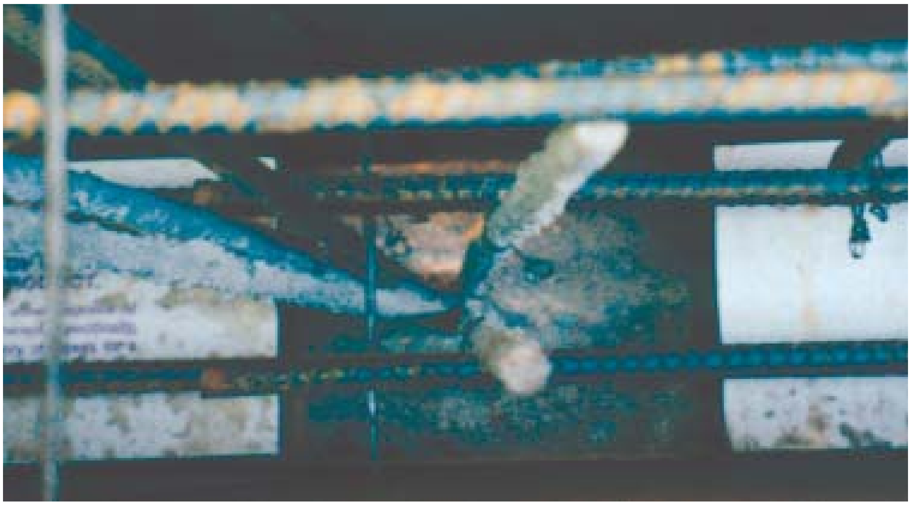


Figure 6. In a top view into the forms just before the concrete pour, the void forms are visible at either side of the caisson at center (above). The vertical strands of rebar extending from the caisson will anchor the foundation wall to the caisson, which will bear the structure's weight. After the forms have been stripped, the edges of the void forms are visible at the base of the wall, except where interrupted by caissons (left).

Floating Walls

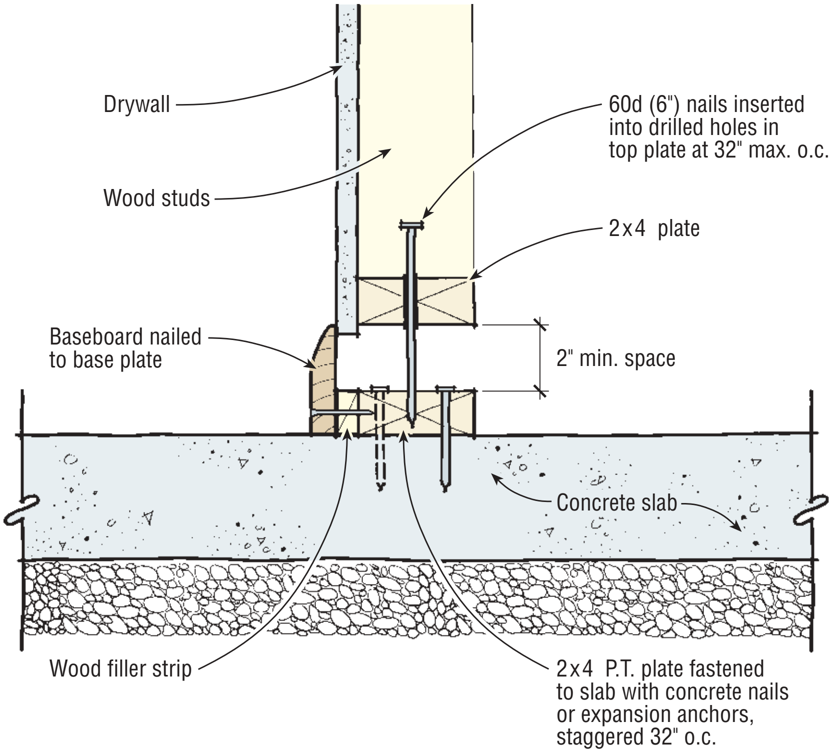


Figure 7. Where basement slabs are used in expansive-soil areas, a "floating wall" detail is used to prevent possible heaving from displacing the floor above. A pressure-treated sill plate is powder-fastened to the slab. The partition wall, which is constructed 2 inches shorter than the height of the basement, is temporarily positioned with wedges between the treated sill plate and the bottom plate of the wall. After the top plate has been nailed to the overhead joists, a 60d spike is driven into a slightly undersized predrilled hole in the bottom plate of the partition and into the treated sill plate. The baseboard is nailed to the sill plate but not the wall itself, so any movement of the slab will not distort the partition.

base of each wall form, except over the caisson heads that serve as the load-bearing points for the structure. These manufactured void forms, which friction-fit between the sides of the forms, are something like heavy cardboard box stock and come in standard widths — most often 8 inches wide by 4 or 6 inches tall (Figure 6, previous page). Holding the void material back from the caisson heads permits the wall or grade beam to bear directly on the caissons and encase the protruding reinforcement.

Although the void material stays rigid throughout the concrete pour, it soon breaks down upon exposure to soil moisture. If — or more likely when — the expansive material below the walls swells, the resulting open space lets it do so without exerting any pressure on the concrete. The wall is unaffected, because it is entirely supported by the caissons.

Once the voids are in place, the other side of the form can be set and braced. We're careful to leave the caisson tops clean before closing up the wall, because these areas are difficult to get to later. We also make one final check for any embedded foundation hardware called for in the plans, such as hold-downs, strap anchors, and ties. Standard anchor bolts are usually wet-set, so we make sure we have the right size on hand before the concrete pump shows up to fill the forms.

Structural Wood Floors

The lower level of a finished space can be floored with a concrete slab if the soils report permits, but we're not fond of that approach. Even when the slab is completely isolated from the foundation walls and isolated from potential problem soils with an aggregate base, the possibility of heaving and cracking can't be completely ruled out. (Expansive soils usually extend so deep that it's impractical to remove them and put down clean fill in their place.) When a slab floor is used, a time-consuming "floating wall" detail is necessary at partitions to minimize damage if the slab does heave (Figure 7).

Figure 8. Steel saddles, expansion-bolted to the foundation walls, support the ends of the central girder in the crawlspace (above). The ends of the I-joists rest in joist hangers fastened to pressure-treated ledgers (right).

We prefer to use structural wood floors — floor systems that are suspended from the concrete foundation walls to eliminate any contact with expansive soil. The code-required 18-inch clearance between the soil and the underside of the joists provides an ample cushion if the soil does swell. The space also simplifies routing plumbing and other mechanical systems.

Floor framing. Because the foundation walls are attached to the ground only at the caissons, which are ordinarily spaced 10 to 15 feet apart, the structural floor also provides essential bracing for the foundation. To get that bracing in place as quickly as possible, we have the lumber package for the structural floor and the structural steel delivered to the site at the same time and have a crane set everything down inside the basement.

One or more steel I-beams are attached to the foundation walls with steel saddles that are expansion-bolted to the walls, with intermediate support provided by additional piers (Figure 8). The ends of the wood I-joists are supported by joist hangers fastened to pressure-treated 2x12 ledgers, which are also bolted to the walls.

We let the plumber know when we're almost ready to install the joists. This gives him some incentive to show up on time, because it's much easier for him to rough in the drain lines before the subflooring is in place. Drain lines should always be suspended from the joists with hangers to keep them well clear of the soil, to prevent later soil expansion from reversing the slope and causing backups. When the plumbing rough-in is finished, we glue and screw the 3/4-inch OSB subfloor into place. Solid blocking at all panel edges helps stiffen the floor and increase its resistance to lateral soil pressure.

Waterproofing and Ventilation

To avoid problems with dampness and mold, we grade the soil beneath the floor to slope toward the perimeter drain and carefully seal it with a layer of 6-mil Visqueen, which we buy in 12x100-foot rolls. After clearing away any wood scraps or other construction debris that could puncture the plastic, we lap adjacent sheets by 24 inches and seal the laps with silicone caulk. We also use silicone to seal the plastic to the concrete foundation walls and around the caissons that support the girder. To get a good seal in those areas, we sometimes use a high-quality duct tape from 3M to hold the plastic in place while the silicone cures.

Ventilating the crawlspace. To provide some air movement through the crawlspace, we install a straightforward exhaust-only venting system. A run of 6-inch galvanized duct extends vertically from the crawlspace to the first-floor joist cavity overhead, where it turns and exits through the rim joist. An in-line 180-cfm fan controlled by a humidistat powers the system. Because we also go to great lengths to provide a dry basement, this is something of a belt-and-suspenders approach, but given current concerns about mold, we think it's well worth the effort.

Backfill and Finish Grade

When you're dealing with expansive soil, you can't just toss some corrugated drainage pipe and gravel at the base of the foundation wall and call it a drainage system. We back our perimeter drains with a 6-mil PVC liner that extends along the bottom of the excavation and is turned up at the edge of the foundation wall.

The first step in installing the membrane is to smooth out the drain area and remove any stones, chunks of concrete, loose form wedges, or snap-tie ends that could puncture the liner. We then spray the walls with dampproofing and unroll the 4-foot-wide membrane

Figure 9. To prevent runoff from seeping beneath the perimeter drains, a 6-mil PVC liner is spread at the base of the foundation wall and adhered to the freshly applied dampproofing.

Figure 10. Because expansive soils react to changing moisture conditions, controlling runoff near the foundation is a good way to prevent problems. Gutters and downspouts should direct water away from the foundation, and grass and other water-loving plantings should be kept several feet away from the perimeter.

while the asphalt is still tacky. Caisson-and-grade-beam foundations don't have footings that protrude into the drain area, which makes it relatively simple to turn the membrane up neatly at the base of the wall and stick it to the fresh asphalt (Figure 9).

Finally, rigid 4-inch-diameter perforated PVC pipe wrapped in filter fabric goes on over the membrane. The pipe is covered with at least 10 inches of $^3/_4$-inch washed aggregate and finished with a layer of 15-pound asphalt felt to prevent backfill dirt from clogging the aggregate. Depending on the site, the footing drains lead to daylight or to a sump pit with a pump that discharges the collected water well away from the foundation.

Blended backfill. To reduce stress on the foundation walls and prevent micro-cracking, we delay backfilling until both the lower-level structural wood floor and the main floor are in place to stiffen the walls. Much of the excavated soil from the site is usually too expansive to use as backfill, but if space permits, we sometimes "blend" some of the excavation soils with imported material to come up with a suitable mix. Topsoil, for example, is usually nonexpansive and can safely be used as backfill. If you're not experienced at identifying expansive soils, get some guidance from the soils engineer before using on-site material.

High and dry. To encourage surface moisture to drain away from the foundation, we shape the finish grade to at least a 1-in-10 slope within 10 feet of the foundation, with at least a 6-inch separation between the top of the foundation or siding and the finish grade. The downspouts should be extended at least 5 feet from the foundation with solid pipe or concrete splashblocks.

Landscaping can be another major source of potential moisture problems, so we encourage customers to avoid turf and other plantings that demand a lot of water (Figure 10).

David McMahon *is a general contractor in Boulder, Colo.*