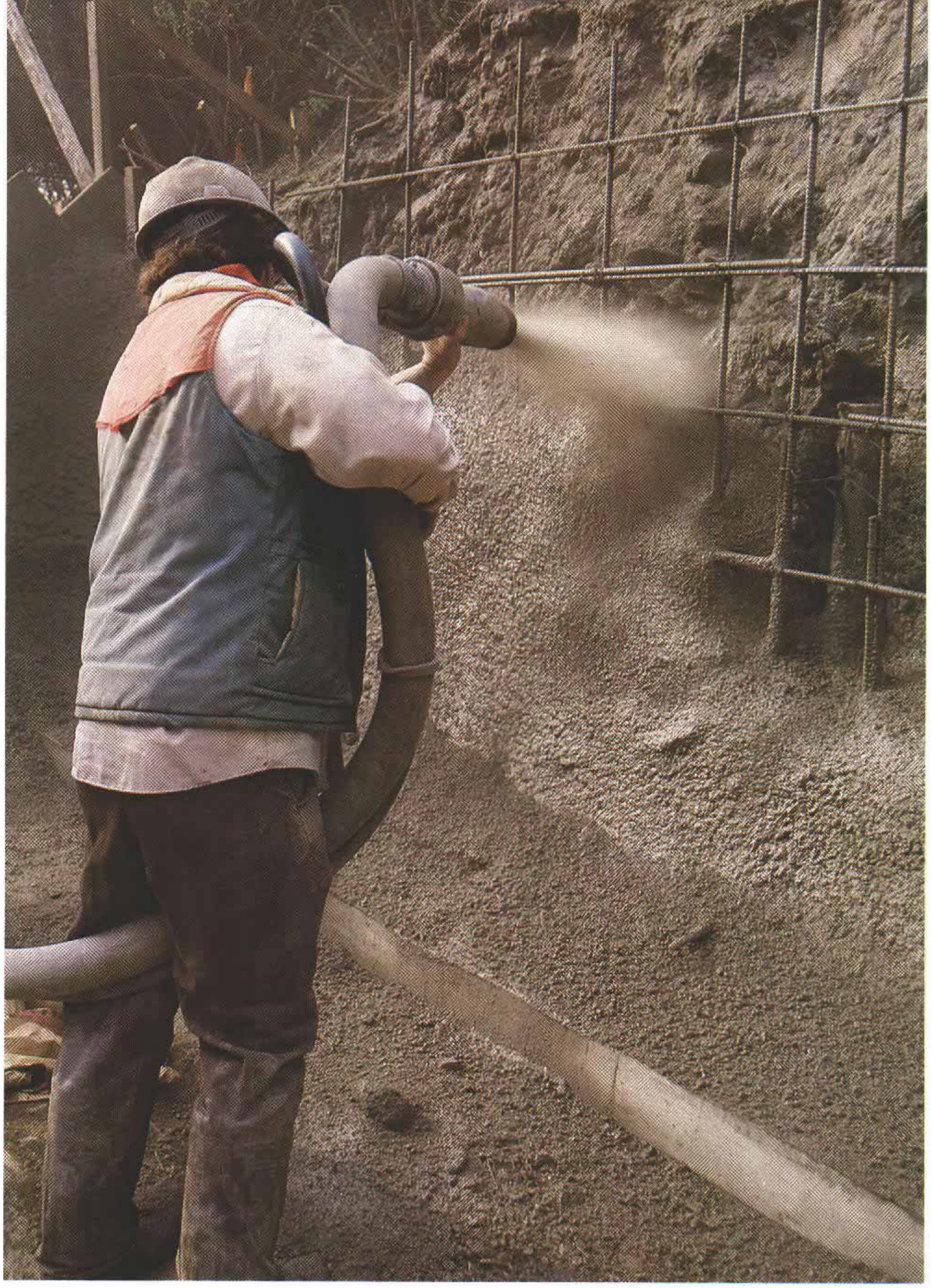


Gunite Retaining Wall

Sprayed-on concrete does more than just line swimming pools

by Ken Hughes

I am a structural engineer who works in the San Francisco Bay Area, and these days a lot of my clients are building on steep hillside lots. The reason is simple enough—all the good flat lots have been taken. For the designer, hillside lots present the challenge of fashioning a building that takes advantage of the views and a floor plan that works in concert with the terrain. On the other hand, the builder is usually faced with extensive excavation work and an unconventional foundation system. But no matter what type of foundation is eventually constructed, these hillside projects often begin with hefty retaining walls.

The wall discussed in this article holds back the earth above a home built by Servais Construction in the Berkeley hills. This company specializes in building finely crafted houses, both on a contract and a speculation basis. Whenever I get a call from Jim Servais, I know I'd better put on my hiking boots to inspect the lot.

As with most of Servais' projects, I was skeptical when I first saw this site. It was almost too steep to walk. Servais wanted to build a spec house on the property, so it was understood from the outset that we had to approach the project with that in mind. If we couldn't figure out a way to stabilize the earth within budget, we would have to abandon the project.

We began by getting a soils report from Subsurface Consultants of Oakland, Calif. They found the soil to be reasonably stable, with weathered bedrock 4 ft. to 6 ft. below the surface. Given this news, we calculated that some excavation near the center of the site would allow a house

Ken Hughes is a structural engineer with the firm of Vickerman/Zachary/Miller Engineering and Architecture in Oakland, Calif.

to be attractively nestled into the hillside. The vertical cuts into the hill, however, would have to be bolstered by retaining walls.

Retaining-wall design—With any retaining-wall design, the objective is to stabilize a vertical cut in the soil as economically as possible, yet achieve a long-lasting structure that satisfies accepted levels of structural safety. For this project, several retaining walls were required. The largest is 50 ft. long and averaged 7 ft. in height with a steep, upward-sloping backfill. This wall is above both the house and the street, about 100 ft. from the nearest driveway.

By looking at test borings from the site, our soils engineer knew that the retaining walls would have to hold back soil made of sandy clay. The wall footings would be in the transition area, where the sandy clay mingles with the weathered bedrock.

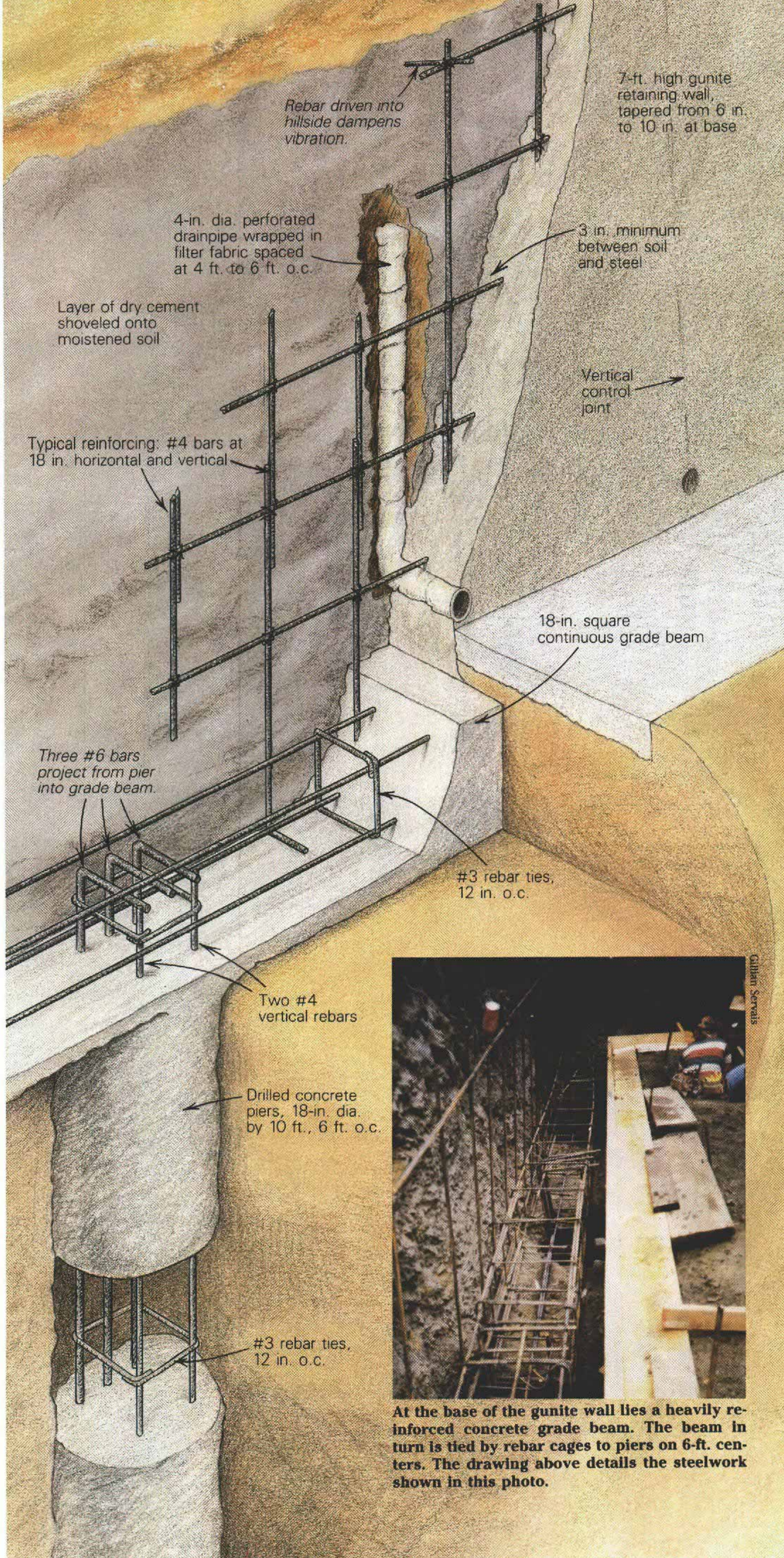
Using this information, I designed two retaining walls for Servais. This way he could run a cost analysis for each design, and pick the more economical solution. Both design's used a conventional continuous-spread footing to resist overturning and sliding. Wall A was a cast-in-place concrete wall. Wall B would consist of concrete blocks, reinforced with steel and completely grouted. We considered two other wall types—a concrete crib wall (precast concrete members stacked together like Lincoln Logs) and one made of pressure-treated timbers. We rejected the crib wall because it would have required another subcontractor to build it, and Servais wanted to keep the cost down by building the wall with his crew. Although there is nothing wrong with pressure-treated wood retaining walls, we vetoed the idea because bank loan officers don't always believe in them.

Modifying the design—When the hillside cuts were made, two things became apparent. First, the 7-ft. vertical cut seemed to hold temporarily without sloughing. This was partly because of a long dry spell prior to excavation. Also, the bedrock turned out to be a little closer to the surface than we expected. We also realized that most of our retaining-wall footing would have to be trenched and placed in bedrock. At this point, we reconsidered the wall's foundation.

We decided to discard the conventional footing because of all the pick-and-shovel excavation it would have required into the stubborn bedrock. Instead, we opted for a reinforced-concrete grade beam atop 18-in. dia. piers, spaced 6 ft. apart (drawing and photo at right). A backhoe could have handled the excavation, but since Servais needed a drilling rig to bore holes for the house foundation anyway, it made sense to avoid the expense of one more heavy-equipment subcontractor.

Footing aside, Servais was not looking forward to building this wall. The labor involved in carrying the concrete blocks up the hill by hand would be time-consuming and expensive, and the alternative of casting the wall in place involved transporting, building, placing and stripping a considerable amount of formwork.

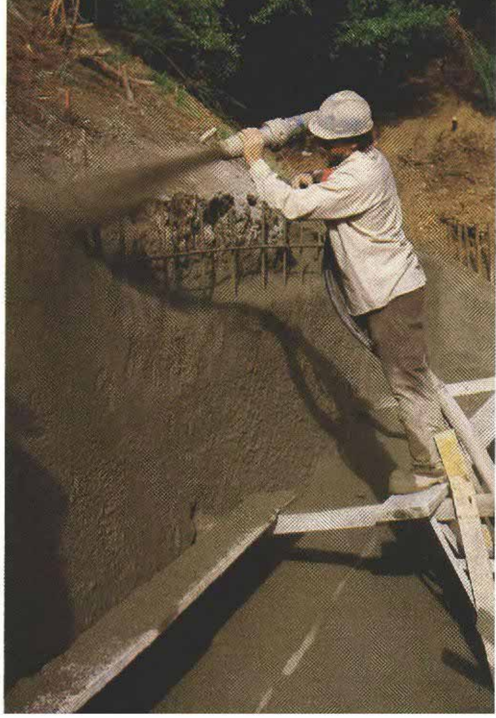
After pondering the blocks versus the pour, Servais called and asked, "Why can't we build



Gillian Servais

At the base of the gunite wall lies a heavily reinforced concrete grade beam. The beam in turn is tied by rebar cages to piers on 6-ft. centers. The drawing above details the steelwork shown in this photo.

Drawing: Chuck Lockhart



Perforated drainpipes let into vertical cuts in the raw earth relieve hydrostatic pressure behind the wall, left. Before the gunite was applied, they were wrapped with filter fabric to keep them from clogging. The white material on the bare earth is portland cement, which helps to prevent sloughing. At the end of the wall, a minimal form turns the corner. Above, gunite is placed in Increments as the operator makes a pass from one end of the wall, then back to the other. The contents of the hose are under tremendous pressure, so it takes a firm, steady grip to control the business end of a gunite hose. If it were to whip about out of control, it could easily injure an unlucky by-stander. A few hours after the gunite crew begins its work, the wall is ready for troweling, below.

this wall out of gunite?" The idea made sense. It took advantage of the temporary stability of the vertical cut, which eliminated the need for a back form. It would considerably reduce labor and time, compared to the concrete block or conventional cast-in-place concrete. From an engineering viewpoint, gunite is nearly identical to cast-in-place concrete (see the sidebar at right). The steel reinforcing, concrete strength and wall thickness would not change significantly. By making some changes in the drainage system, I was able to adapt the new foundation to work with a gunite wall.

A drainage system behind a cast-in-place concrete or block wall is typically installed after the wall is in place. Not so with a gunite wall. In this case the drainage network is a series of vertical perforated 4-in. dia. pipes let into cuts in the earth on 4-ft. to 6-ft. centers (photo facing page, left). To keep the gunite from clogging the perforated pipes, the crew wrapped them with Mirafi 140N filter fabric (Mirafi Inc., P.O. Box 240967, Charlotte, N. C. 28224). The drainpipes emerge at the bottom of the finished wail, relieving the lateral hydrostatic pressures on it. Before shooting on the gunite, the crew temporarily plugged the pipe outlets with rags tied to rebar handles.

Wall construction—Once the hillside had been cut, it was important to get the wall built right away. This was a winter project, and a heavy rain could seriously have eroded the exposed hillside. To help maintain the bare earth cut, the crew applied a thin layer of portland cement to the vertical surface. They did this by lightly misting the wall with a hose, and then scattering shovel loads of dry cement across the cut. This trick did two things: it helped to prevent erosion of the dirt, and it created a surface to which the gunite would more readily adhere.

Next, the crew tied the steel reinforcing rods in place. The steel is the same size and spacing as for a poured concrete wall, with one exception. Reinforcing steel in a gunite wall has to be secured to keep it from vibrating as the gunite is blasted into position. To dampen the vibration of the steel, Servais' crew tied wires to the tops of some of the vertical rods, and then wrapped the wires around rebar stakes driven into the hill. Without this bracing, the steel might have bounced around as the gunite was blasted onto the wall, causing already placed gunite to fall out in big chunks. Except for a couple of small forms for the wing walls at the corners, the wall was ready to shoot.

The entire 7-ft. height was placed in one four-hour operation (photo facing page, right). As they sprayed the wall, the gunite crew monitered its thickness by watching thin horizontal "ground wires" tied to the rebar. As they sprayed the wall, the gunite crew monitored its thickness by watching wire depth gauges tied to the rebar. Typically, the gauges are used as guides for a cutting tool that slices the excess gunite off the face of the wall. This results in a true flush surface. With this wall, however, Servais elected to have a more random finish (bottom photo, facing page) in keeping with the Spanish-style stucco house he planned to build.

As soon as the gunite was in place, the drainline plugs were pulled, and vertical control joints were struck into the face of the wall. These control joints project upward from each weep hole. Once the masonry starts curing and shrinking, cracks usually start at the weep holes. They are therefore natural areas to direct crack-control joints.

The last step was to apply curing compound to prevent rapid curing and cracking of the surface concrete. Except for achieving its design strength—in this case 2,500 psi—the wall was complete. Excluding excavation and footing construction, most of the construction was completed in one day, and there were almost no forms to strip or backfilling to do.

Construction costs—This gunite wall was built for just over $2,000, or roughly $6 per sq. ft. of surface area, excluding footing construction. By comparison, a similar concrete-block wall would have cost roughly $7 per sq. ft., plus the costs of transporting the blocks uphill and applying a plaster finish. We estimate that a cast-in-place concrete wall for this project would have cost $9 to $10 per sq. ft. Building and setting the forms would have been labor intensive and costly, and likely as not the form lumber would have been hard to reuse. Perhaps even more important, Servais didn't have to agonize over a tall-wall concrete pour into forms that would have been braced on just the downhill side. □

Gunite and shotcrete

Until 1967, the word "gunite" was a proprietary trademark. It is now a generic term used to define the dry-mix shotcrete process. In this procedure, a dry mixture of cement and fine aggregate is pumped through one hose and water through a second. Mixing occurs at a common nozzle where the gunite is ejected at high velocity onto a surface.

"Shotcrete" is a generic term used to describe the pneumatic placement of any concrete through a hose and nozzle at high velocity. While the term properly covers both the wet-mix and dry-mix processes, the word is used most often to describe the pneumatic placement of concrete in a plastic state.

Recent improvements in the pumps that deliver shotcrete to its target have made it the choice over gunite in some circumstances. While a gunite crew can typically move about 30 cu. yd. of material in a day, a comparable shotcrete outfit can pump about 90 cu. yd. Gunite, however, can be trimmed to a smooth surface, while shotcrete leaves a rough finish that is often plastered for cosmetic purposes.

***The birth of gunite*—Although gunite and shotcrete came into wide use immediately after World War II, gunite dates back to the turn of the century. In 1895, Dr. Carlton Akely, Curator of the Field Museum of Natural Science in Chicago, developed the original cement gun. He was searching for a method to apply mortar over skeletal frames to form the shapes of full-size prehistoric animals. He could not form the necessary convoluted shapes and contours by conventional troweling, so he developed a method to shoot concrete into place with air as the propellant. In a single-chambered pressure vessel, he placed a mixture of sand and cement Then he pumped compressed air into the chamber, forcing the mixture into a hose. As the sand and cement mixture was ejected from the end of the hose, it passed through a spray of water that hydrated the mixture.**

Immediately following World War II, the use of gunite and shotcrete increased tremendously. Builders found numerous applications in all sizes of projects, from swimming pools to tunnel construction.

Although procedures have been refined and equipment improved, the basic process has not changed since it was originally developed. Gunite or shotcrete can be used in lieu of conventional cast-in-place concrete in most instances, the choice being based upon convenience and cost. These processes are particularly cost-effective where formwork is impractical, or thin layers or variable thickness are required. The principles used in the design of cast-in-place concrete structures are also applicable for gunite and shotcrete structures. Compressive strengths of 2,000 psi to 4,000 psi are common, and higher strengths are easy to attain, depending upon the specific mix design.

Although large civil and industrial projects such as dams, tunnels and aqueducts are the most common use for gunite and shotcrete, other modern applications that are becoming more popular include seismic renovations, basement and shear-wall construction in new buildings, and soil nailing. Old masonry buildings can be strengthened to resist seismic forces by applying reinforcing steel and gunite to the face of the brick, thus forming a strong wall attached to the much weaker masonry. This is usually done on the inside face, which allows the exterior rustic brick facade to remain.

Soil nailing is a relatively new procedure that allows construction of very high retaining walls without the need for a footing or vertical piles. This is a common way to stabilize a deep excavation, such as the perimeter basement walls of underground parking structures below high-rise buildings. This process involves reinforcing the earth by drilling and grouting into place an array of tie-back anchors, typically to a 30-ft. depth. The exposed ends of the rebar strands protruding from the anchors are woven into a reinforced gunite or shotcrete wall that forms the vertical surface of the excavation.

Gunite and shotcrete placement are very specialized operations. The quality of the product is highly dependent on the skill of the workers. The American Concrete Institute (Box 19150, Redford Station, Detroit, Mich. 48219) has prepared and made available "Guide to Shotcrete" (ACI-506R-85), which gives detailed guidelines and requirements for successful gunite and shotcrete placements. In addition, the Gunite and Shotcrete Contractors Association (P.O. Box 44077, Sylmar, Calif. 91342) has vast resources of technical data to aid contractors and engineers in the use of gunite and shotcrete. —*K. H.*