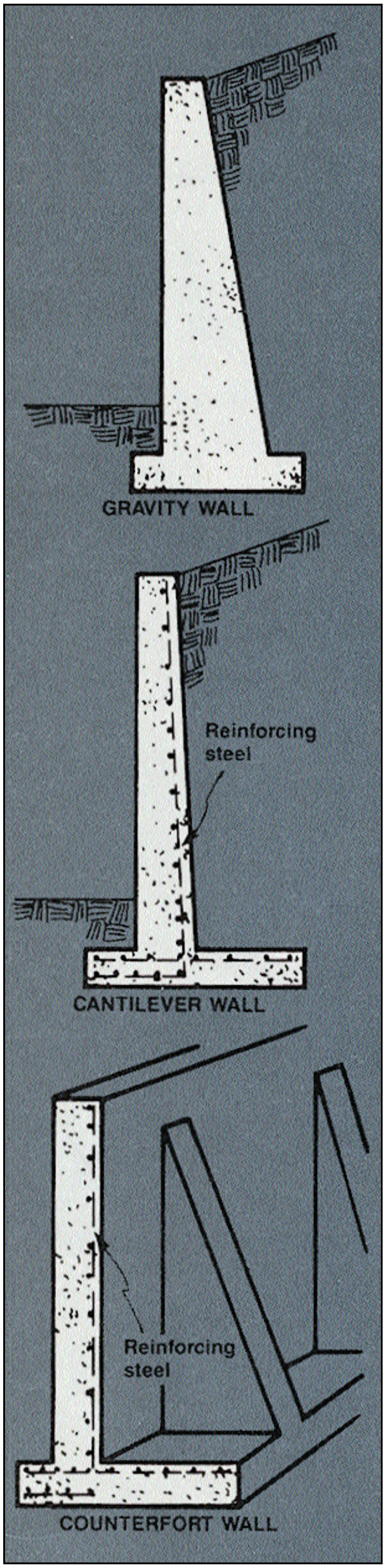
The many types of concrete retaining walls

Newer concrete retaining wall systems can cut the cost of cast-in-place walls in half



Cast-in-place walls have been built since about 1900, but now they usually are economical only for low walls.

Traditional cast-in-place concrete retaining walls are fast becoming untraditional. They cost too much (often more than $60 per square foot) and take too long to build. Newer concrete wall systems have replaced them in many instances. The newer systems are less costly and quicker to build. Many require less excavation and cause less traffic disruption. Some have been used for more than 20 years; others are being introduced now.

Why are they necessary? Retaining walls support highway fills or cuts where there's not enough room alongside the highway for an unsupported slope. They're often used in cities to keep highway expansions within existing right-of-ways. In the wilderness, they minimize the impact of the highway on the environment. Constructing an unsupported slope often can severely scar the landscape. Many bridge abutments and some building foundation walls also are built as retaining walls.

Traditional cast-in-place walls

Contractors have built cast-in-place walls for more than 100 years. There are three types: gravity, cantilever, and counterfort (see drawing). Each of these walls is constructed with a base slab or footing.

The gravity wall relies mostly on its own weight to resist earth pressure. It usually contains no reinforcement. The wall often has a trapezoidal cross-section, but the front or back face may be stepped to make it easier to place concrete. A stepped back face also provides more ground surface at the top of the wall.

The wall portion (or stem) of a cantilever wall cantilevers from the base slab. The wall is thinner than a gravity wall, but it's reinforced along the back face and in the base where loading induces tensile stress. For tall walls, cantilever walls are usually less expensive to build than gravity walls.

In counterfort walls, the base slab and wall span between vertical triangular braces. These concrete braces are called counterforts if they're on the earth side of the wall. If they're exposed at the front, they're called buttresses. The wall, braces, and base are reinforced. In thickness, the wall itself is similar to a cantilever wall.

In researching this article, we learned about more than 20 proprietary concrete retaining wall systems. Many are described here. In Part II, which will appear in August, you can read about precast retaining walls that do not rely on soil reinforcements or ground anchors for support. Even so, we're certain these articles don't cover every existing system. If you know of another concrete retaining wall system, please write and tell us about it.

Cast-in-place walls are much more expensive than many of the newer retaining wall systems described below. They also take more time to construct. To maintain traffic flow on roadways, you often need to build temporary supports while building the permanent wall. These supports must stay in place all the way through the job: while excavations are made, footings are placed, formwork is constructed, reinforcing steel is tied, walls are placed, concrete is cured, forms are stripped, and walls are backfilled. Often these walls are located in a confined area with limited access making construction even more difficult and time-consuming. As a result, cast-in-place walls are used mostly for low walls now.

For more information about small gravity wall design, read "Small Gravity Retaining Walls" in the November 1984 issue of *Concrete Construction,* pages 977-982.


Constructed from the top down, a ground-anchored wall is especially suited for cuts. The wall face can be shotcreted, cast in place, or (as shown here) precast.

Mechanically stabilized earth (MSE) walls

The earth backfill behind a concrete wall facing can be made to support itself by layering reinforcement within the backfill. The soil itself becomes a self-supporting structure. If metal strips are used as reinforcement, the tensile stresses in the soil transfer to the reinforcement through friction. If mesh is used, the transverse wires of the mesh resist the tensile stresses in the soil. In either case, the soil itself withstands the compressive and shear stresses. The concrete facing prevents the face of the soil from raveling and provides an attractive facade.

At least four proprietary MSE systems are available in the United States. One has been used here for 15 years. Georgia and California state transportation departments also have developed their own systems which contractors bidding jobs can select as alternatives to the proprietary systems.

Each system has three main parts: the concrete facing, backfill, and reinforcement. Individual systems vary mostly in the type of facing and reinforcement and the way these are connected.

In one system, ribbed, galvanized metal strips are bolted to metal tabs embedded in the back face of 5-foot-high cruciform-shaped precast facing panels. In another, coil bolts at the ends of special welded wire mesh are threaded into coil inserts in 5-foot-high, hexagonal precast facing panels.

Another system accepts a precast or cast-in-place face. Joints between the 12 1/2/x2-foot precast facing panels grip the ends of the galvanized welded wire mesh soil reinforcement. Or the mesh is bent up at the face of the wall and used as reinforcement for the concrete facing cast directly against the soil embankment.

In yet another system, plastic mesh made of high-density polyethylene reinforces the embankment, which is faced by full-height precast panels up to 25 feet high. Plastic rod or pipe connects the mesh reinforcement in the soil to mesh tabs embedded in the facing panel.

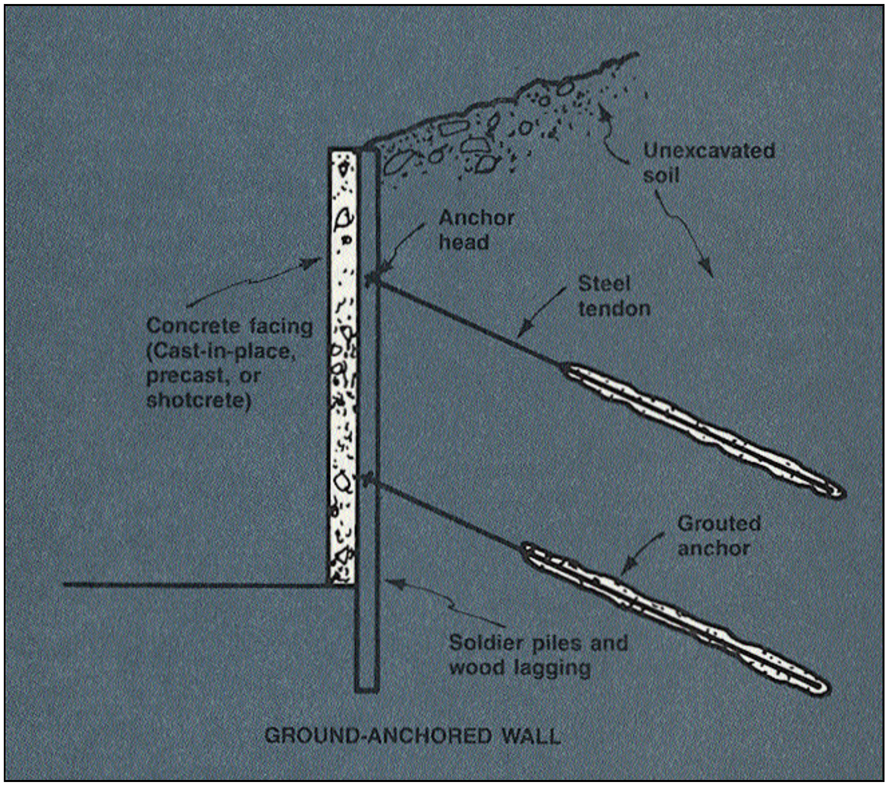
Although native soils reportedly can be used with this plastic mesh, most MSE systems require granular backfill. Fine-grained cohesive soils, such as clay, usually are not allowed because of poor friction, drainage, constructibility, and corrosion concerns.

The length of the soil reinforcement varies depending on wall geometry and loading, but generally it must be 70 to 100 percent of the wall height. This usually makes MSE walls too expensive for earth cuts. The excavation behind such a wall would have to be at least as wide as the length of the soil reinforcement.

For walls that support fills, however, MSE systems are very cost competitive. According to the Federal Highway Administration (FHWA), they can cost 30 to 50 percent less than conventional cast-in-place walls and provide similar savings in construction time (Ref. 1).

Ground-anchored walls

Ground-anchored walls are thin concrete retaining walls that are permanently anchored to firm ground by grouted ties. The bar or strand ties are called *permanent ground anchors* or *tiebacks.* They generally are inserted into holes that are drilled or driven into the existing soil or rock behind the wall. The ends of the steel ties are grouted,



Grouted steel tendons tie the concrete face of a ground-anchored wall to the unexcavated soil behind the wall.

then the grouted ground anchors are post-tensioned. The anchors must be long enough so the grouted ends rest behind the critical failure surface in stable soil or rock. The soil behind the wall is not removed.

Because specialty contractors have developed most ground anchors, many of the techniques are proprietary. However, construction usually begins by installing columns or soldier beams.

Workers drive or drill the soldier beams into the ground. The soldier beams serve as vertical strongbacks for the wall. Then the workers excavate the earth in front of the soldier beams as deep as the first row of ground anchors. After installing the first row of ground anchors, they excavate to the next row. At each step in the excavation, they place wood lagging between the soldier beams to temporarily retain the wall. This process is repeated until the full height of the wall is exposed. After completing the excavation and installing the ground anchors, the soldier beams, lagging, and anchor heads are covered with a cast-in-place, precast, or shotcrete facing.

The concrete facing of a ground-anchored wall is thinner than a cantilever wall, which means it also requires less excavation. A ground-anchored wall with a 7-inch-thick concrete face can support a 40-foot-high cut. Because the soil behind the wall is not excavated, anchored walls do not require wide aboveground construction easements. This makes them especially suited for constructing depressed highways next to roadways, as is common at interstate underpasses in cities. Because the wall can be constructed from the top down, traffic on adjacent roadways does not have to be interrupted. Ground-anchored walls eliminate large footings and foundation piles under the wall, too.

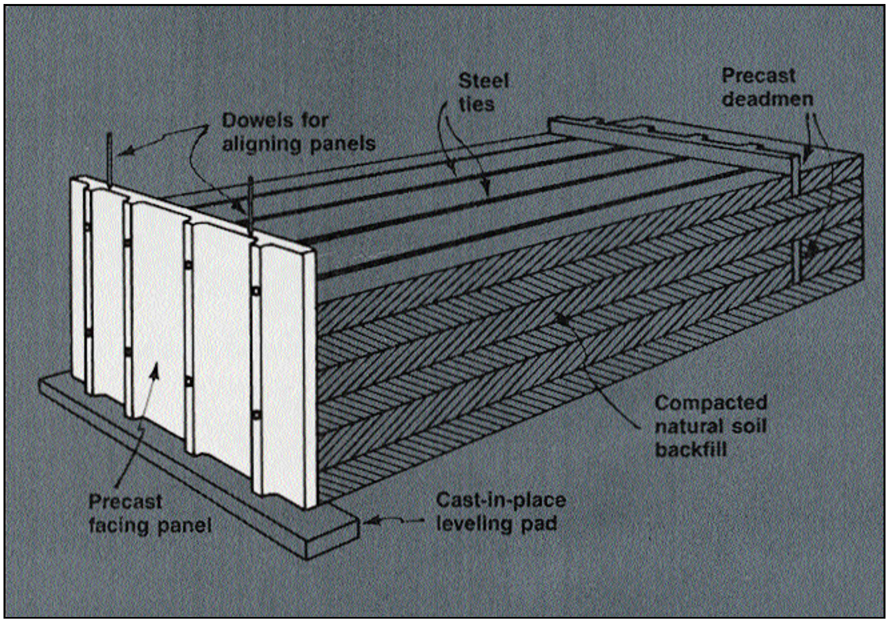
Ground-anchored walls do have limitations, however. They cannot be used in soft cohesive soils because of excessive creep. Existing utilities, subways, or other underground structures may prohibit the use of anchors, though sometimes these obstructions can be avoided by varying the locations and angles of the anchors. Also, permanent underground easements must be obtained for behind the wall. The site can be developed aboveground but only if this does not interfere with the ground anchors below.

Soil nailing

Soil-nailed retaining walls are designed like MSE walls but constructed like ground-anchored walls. Like MSE, nailed soil acts as one coherent gravity mass. Long steel rebars are inserted in the ground at close enough spacing to make the soil more self-supporting. The rebars reinforce the soil in the same way MSE reinforcements do, only they are installed in natural unexcavated soil, not select compacted backfill.

Like ground anchors, these rebars are inserted into drilled holes and grouted. But unlike ground anchors, the full length of each rebar is bonded to the soil, not just the end. Because they don't have to resist high lateral earth loads pressing against the wall, the rebars are not post-tensioned as ground anchors are. Nailed soil, like MSE, exerts much less pressure on the concrete facing. Consequently, the precast, cast-in-place, or shotcrete face can be as thin as 5 to 8 inches.

In 1985, the FHWA sponsored the construction of a soil-nailed wall for a tunnel portal at the Cumberland Gap. After making a 5- to 6-foot-deep cut with a bulldozer, workers placed vertical strips of drainage fabric over the soil every 15 feet (5-foot spacings are now recommended). Then they sprayed shotcrete over the cut and allowed it to cure for 1 day. Next, they drilled 4½-inch-diameter holes into the cut on a 5-foot grid. The holes were 20 to 30 feet deep and 15° from the horizontal. They inserted #8 and #11 rebars in the holes and grouted them with neat cement grout. After the grout set, tightening a nut at the end of each bar applied a slight torque to it. Then the workers applied a second



Steel ties anchor large precast facing panels to precast deadmen buried in the backfill. Unlike most MSE systems, this system usually does not require select backfill.

layer of shotcrete, this one reinforced with wire mesh. After another level of excavation, they repeated these steps until the 40-foot-high wall was complete.

At least seven permanent soil-nailed structures have been built in the United States. Soil nailing can increase the safety factor of a slope without removing the sliding soil. Or, as at the Cumberland Gap, it can stabilize a cut hillside in a landslide-prone area without using temporary shoring. Soil nailing usually requires less underground easement than ground-anchored walls do.

Soil-nailed walls also can support excavations for building foundations. At least 100 of these temporary walls have been built in the United States.

Precast panels anchored by precast deadmen

Although this system is constructed much like a MSE wall, it acts more like a grouted ground-anchored wall. Epoxy-coated steel tendons connect precast concrete face panels to precast concrete deadmen buried in the backfill. The deadmen resist the lateral earth loads that press against the concrete facing. Because the tendons don't reinforce the soil, poorer quality onsite soils can be used as backfill. As a result,

HOW DO YOU DECIDE WHICH TYPE OF WALL TO USE?

Owners can achieve tremendous cost savings by providing alternative retaining wall systems that bidders can choose from. State highway agencies generally provide complete plans for all workable alternatives (some of which are supplied to the agency by the manufacturer of the wall system), then the contractor can choose which alternative is most economical for him. Here are some of the considerations that will affect that decision:

- *Availability of materials.* Must wall components or select backfill be shipped from too far a distance?
- *Availability of specialty contractor.* A permanent ground-anchored wall might be the most economical solution, but only if there is an experienced contractor in the area.
- *Environment or aesthetic requirements.* Some wall systems can be planted from top to bottom, and some can economically display a variety of architectural faces. But some walls also require a large amount of excavation, which might leave an unacceptable scar on the landscape.
- *Necessary service life.* The minimum design life for highway retaining walls is generally 75 to 100 years. Industrial sites might need a wall for only 30 years.
- *Loading requirements.* In addition to backfill, will the wall have to support a building or a highway or a truck ramp on top of the backfill?
- *Settlement.* Can the wall tolerate the amount of soil settlement that's expected?
- *Ease and speed of construction.* Unskilled labor is obviously less costly than skilled labor. Quicker construction shortens the disruption to traffic and the worker exposure to traffic. It also reduces traffic control costs.
- *Adaptability to field changes.* If soil conditions are found to require it, the load-carrying capacity of a permanent ground-anchored wall can be increased easily by adding more anchors.
- *Wall height.* Some wall systems are economical only for short walls, and some are economical only for tall walls.
- *Cut or fill.* For walls that support earth at a cut, systems that require little excavation behind the wall face are generally less expensive. Permanent ground-anchored walls, cast-in-place walls, and many precast wall systems are built in this manner. Mechanically stabilized earth (MSE) systems are generally cost competitive when the wall supports a fill.
- *Amount of labor required.* Some systems require more labor than others. One permanent ground-anchored wall contractor says precast facings are cost competitive for ground-anchored walls in the northeast United States. In the southeast where labor costs are lower, he says cast-in-place facings are more economical.
- *Underground easement unobtainable.* Permanent ground-anchored walls and MSE systems require permanent underground easements behind the wall. Cutting the ground anchors or the MSE reinforcements would cause the wall to fail.

this system can cost 30 percent less than MSE systems, says its inventor.

To accommodate 8-inch backfill lifts, the ribbed face panels are made 8 feet long by 64 inches high. First workers set the panels on a concrete leveling pad. Then they backfill to the elevation of the first deadmen, which measure 8 feet long and 20 inches high. Next they install the steel ties. They screw one end of each tie into one of the nuts embedded in the ribs of the facing panels. They pass the other end through a hole in the deadman and then tighten it with a nut. Then, in sequence, they install more backfill, deadmen, and facing panels. Two deadmen anchor each facing panel. Dowels connect the panels to the leveling pad and to panels above and below them.

In the 5 years this proprietary system has been available, walls up to 35 feet high have been constructed. A precaster can obtain rights to use the system as a permanent licensee or for a single job.

—by Mark Wallace

Reference

1. Leary, Robert M., and Gary L. Klinedinst, "Retaining Wall Alternates," Federal Highway Administration, November 9, 1983.

Editor's note

Part II of this article will appear in August. Several precast systems will be described, including crib, bin, cantilever, counterfort, and small block walls.