

LOW RETAINING WALLS

How to overcome nature's desire to topple your wall

The problem is a familiar one to most builders and designers. The ground surface at one location has to be higher (or lower) than at some nearby point. There isn't enough horizontal distance between those two points to drop the grade with a conventional 1:2 slope—or flatter if it's to be a mowable lawn—so the solution is some type of a retaining structure.

Numerous choices are available. They range in complexity from simple gravity structures that rely on their own dead weight to prestressed tie-back systems and reinforced earth embankments.

Generally speaking, the higher the wall the more complicated are the design problems. The total horizontal thrust of the soil behind the wall increases in direct proportion to the square of the wall's height. And the *overturning moment* (the tendency of the structure to rotate about its toe in the downhill direction) is proportional to the height cubed. Thus, a 10-foot high wall has an overturning tendency about its base 8 times that of a 5-foot high wall.

It follows, therefore, that common-sense construction should quickly give way to a completely engineered design when the height of the wall exceeds a certain limit. That limit probably varies from case to case, but it's common to define low retaining walls as those holding back no more than 4 or 5 feet of soil, while anything higher is considered a high wall.

The following is a look at low walls—common types, some design considerations, and ways to prevent and sometimes correct failures.

Forces to Contend With

Before selecting a wall type, one should consider the forces that will or could act to tip it over. Once they've been recognized, it's a question of how best to deal with them—or how to eliminate them altogether.

Lateral Soil Pressure. Water held back by a vertical wall exerts a hydrostatic pressure at any point equal to 62.4 times the depth of water at that point. (The weight of a cubic foot of water is 62.4 pounds.) Soil against a wall will



Precast Loffelstein blocks are set in a staggered arrangement to form a low retaining wall. The blocks—designed to support plantings—are available from Silidur North American Co., Illyria, Ohio

exert a similar pressure—equal to the unit weight of the soil times the depth—but you must also multiply by a factor called the *lateral pressure coefficient*, which equals about 1/3 for a typical sand. Sand fill is usually a reasonable design assumption, since it is always wise to backfill the wall with a granular material—for reasons we'll see later. The lateral pressure diagram, shown in Figure 1, depicts a simple gravity wall with sand or gravel backfill.

If water builds up behind a retaining wall to the point that it completely fills the void spaces in the soil, then the force against the wall equals the hydrostatic force of the water plus the force of the soil. Although the soil pressure will be reduced due to the buoyancy of soil particles, the net result of saturated soil is a much larger total pressure against the wall.

Thus, it's imperative that you not let water build up behind the wall. A well draining sand or gravel backfill is the first step. The second is to provide outlets such as weep holes, which are typically spaced 4 to 6 feet apart in concrete walls. These should have a filter system behind them. A 1/2-inch mesh galvanized wire cloth at the opening, in front of a bed of crushed stone, is a good approach. A perforated subdrain run laterally behind the base of the wall makes an excellent drainage system, in which case the weep holes serve as back-up outlets. The subdrain should have a good outlet at one or both ends of the wall.

Frost. A major, and often underestimated, hazard in northern climates is frost heave. This problem, caused by the formation of ice lenses in silty soils, usually results in an uneven ground surface—especially in paved areas with no

insulating snow cover. As countless individuals who have built structures on wet silty soils can attest, frost heave seems capable of lifting almost anything—or pushing over a retaining wall.

Again, the best approach is: don't try to combat it, eliminate it. And again, the first rule is to backfill with a sand or gravel—but with one added stipulation. The backfill should have no more

than 5-percent silt content—the amount passing a #200 sieve. That seems to be the cutoff. More than 5- or 6-percent silt and the soil becomes frost active. Use the clean non-frost-active material for a 4- or 5-foot distance behind the face of the wall—combined with good drainage—and you should be free of this troublesome problem.

If the native soil is a wet silt or silty sand, it's a good idea to place a layer of

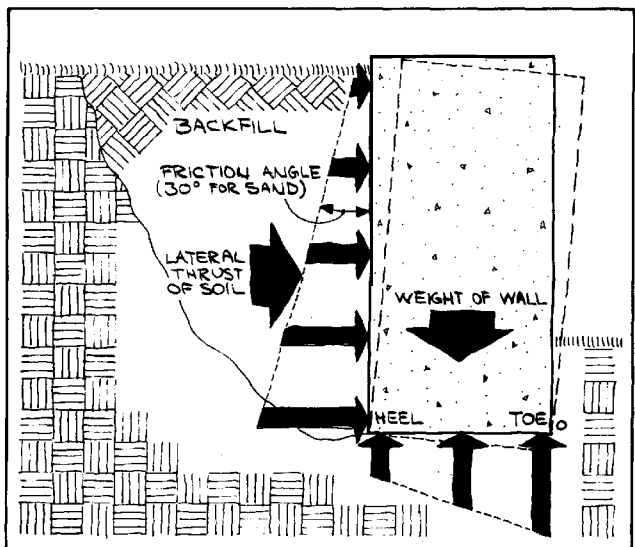


Figure 1. Gravity wall. This shows the major forces at work in a simple gravity wall. The lateral pressure (shown by the width of the triangle) is greatest at the bottom of the wall. The total lateral force (F) is equivalent to the area of the triangle. (F) exerts an overturning moment about the toe (point O), while the wall's weight (W) counteracts it with a resisting moment.

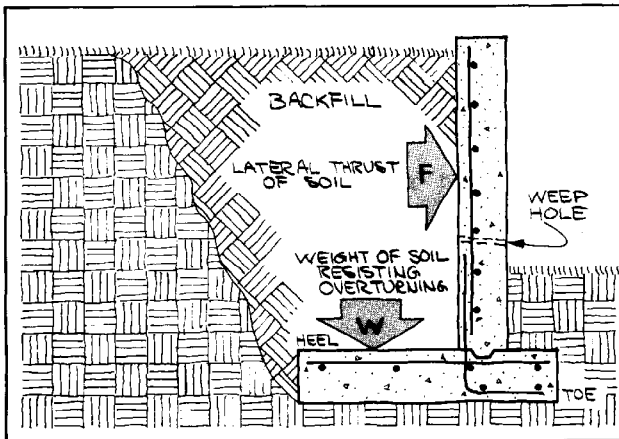
non-woven filter fabric between it and the granular backfill. This will prevent the silt from contaminating the backfill.

Don't forget that frost can also heave the wall upward if the ground beneath the footing is frozen. Thus, it's always best to set the structure below the maximum depth of frost penetration in any given region. That can be 5 or 6 feet in the northern reaches of New England.

Soil-Bearing Pressure. The vertical weight of the wall (W) in Figure 1 plus the lateral force (F) against it results in pressure exerted on the soil beneath it. As one can quickly visualize, the pressure is greatest at the toe (point "o"), the point about which the wall would like to rotate. The pressure here should not exceed the maximum bearing capacity of the soil beneath or the wall will settle and rotate. Soil-bearing capacities can vary from several hundred pounds per square foot in soft soils to several tons per square foot in dense gravels or glacial till. The wider the footing, the more the pressure will be distributed.

In soft soils, or in wet conditions, it may make sense to place a 6- to 8-inch layer of crushed stone under the footing—preferably over a filter fabric—to improve the surface bearing and provide a working mat to avoid disturbing the native soil during construction.

Finally, a word about overturning. Again looking at the gravity wall in Figure 1, imagine the force of the soil trying to rotate the wall about the toe. Counter that with the resisting or stabilizing moment of the weight of the wall. Obviously, if the acting moment is greater, it wins the battle of forces and the wall topples over. Increasing that resisting moment, either by widening the footing or increasing the weight of the wall, is the name of the game. A sloping backfill or other surcharge (such as a parking area, building, etc.) behind



the wall increases the load and demands a stronger design. Again, on anything but the simplest of structures and backfill conditions, it's best to consult with a qualified engineer before proceeding.

The Choices

Now let's look at some of the options available. Bear in mind that while cost is usually a big factor, appearance is also important.

Low retaining walls generally fall into two general categories: cantilevered structures on the one hand and gravity ones on the other. The former rely on internal strength to resist bending; the latter basically count on dead weight to offset the tendency for overturning.

A third category involves anchored walls, and a fourth system uses mechanically stabilized (or reinforced) backfill. These usually involve higher walls, and are not considered here.

Reinforced-concrete cantilever wall. This is the old standby—combining the use of tensile reinforcement with an economical cross-section of concrete, and using the dead weight of the soil above the heel of the footing to counteract the overturning tendency. Figure 2 illustrates the typical configuration, the forces involved, and the proper placement of reinforcing steel.

As one can quickly see, the location of the steel is critical. The top side of the footing under the backfill is in tension, as is the backside of the wall and the bottom side of the footing at the toe. Thus, the main steel must be on those faces, (allowing for at least an inch and a half of concrete cover). Failure to have continuous steel from the footing into the wall would be to invite the wall to push right over. Careless placement of the dowels, near the center or even on the downhill face of the wall—or just plain omitting them—has been the cause of many failed or badly leaning walls.

As a rule of thumb, the footing width should be about half the height of the wall above the footing.

The Concrete Reinforcing Steel Institute's (933 North Plum Grove Road, Schaumburg, IL 60195) *CRSI Handbook* lists proper steel sizes and concrete dimensions for various wall heights and backfill conditions. Don't forget that a reasonable amount of horizontal steel (#4 bars at 10-inch spacing for an 8-inch wall) is needed to combat those ugly vertical shrinkage cracks. Periodic construction joints, or vertical chamfer strips, can also be used so that any cracks that appear in spite of the steel will at least lie in an orderly pattern.

Steel or aluminum sheet piles. This form of cantilever wall counts on the

vertically embedded section to anchor the above-grade portion. While steel sheet piling is usually thought of in terms of temporary bracing for deep excavations, there are light-weight steel and aluminum sections that can be driven with small impact or vibratory hammers.

This can be a nice way to save a low bank that's constantly eroding along a shoreline. The big unknown that has to be addressed first, however, is the subsurface soil conditions. As a general rule, a straight cantilever sheet pile should be embedded to a depth twice the height of the soil being retained. Thus, to retain 5 feet of soil, 15-foot sheets would be needed. Enough exploration needs to be done beforehand to ascertain that (1) the subsoils are reasonably firm, and (2) that cobbles, boulders, glacial till, or bedrock will not impede or prohibit the driving of the sheeting. Nothing can be more discon-

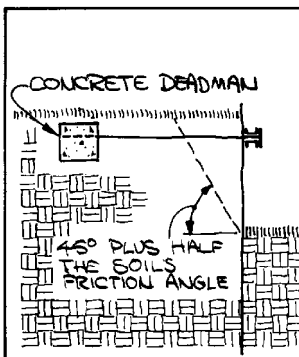


Figure 3. Anchored sheet piling. Steel or aluminum sheet piling is useful for holding back a low bank that's eroding near a shoreline. Typically, the piling should extend twice as far into the ground as above ground. The embedment depth can be reduced by periodically tying back to deadmen, as shown. Deadmen must be far enough back from the wall to lie well outside of the "zone of failure." The zone roughly follows an angle off the horizontal of 45 degrees plus half the soil's friction angle.

certing than to mobilize all the materials and equipment to drive sheet piling, only to discover that bedrock prevents driving to the proper embedment depth.

A variation on the straight cantilever wall uses periodic tiebacks to a "deadman" anchor in the backfill—as shown in Figure 3. Anchors can reduce the required depth of embedment, since the piling is now supported at two points. A

Figure 2. Cantilever concrete wall. This old standby combines tensile reinforcement with an economical cross-section of concrete. The dead weight of the soil above the heel of the footing counteracts the overturning force. The location of the steel reinforcing is critical for success, since concrete has little tensile strength.

common mistake here is to get the anchorage too close to the wall—near the potential zone of failure. To locate the failure zone on a drawing, construct a line at an angle off the horizontal of 45 degrees plus half the friction angle of the soil. For typical soil, the friction angle is about 30 degrees. The deadman must be well behind that possible failure zone to be effective, otherwise it's only part of the problem.

Next come the various types of gravity walls, which include cribs, gabions, precast concrete blocks, and stone walls. Some of these are proprietary systems, and in many cases design assistance is available in the form of tables and charts published by individual manufacturers or trade associations.

Timber crib walls. For low walls, pressure-treated timbers can be both versatile and attractive. The key to a successful timber wall of any significant height is to make it in some sort of a crib that can be filled with soil for dead weight. This can vary from an occasional timber "return" into the backfill for very low structures (1 to 2 feet) to a more complete box or crib in higher ones.

What doesn't work very well is a series of timbers placed one atop the other—even if they're spiked together—in a single vertical plane. Without the crib effect to make it act like a true gravity wall, there's little hope that the combined efforts of soil pressure and frost won't eventually push it over, or at least move it far enough out of plumb to threaten its stability.

Without the crib effect, there's little hope that the combined effects of soil pressure and frost won't eventually push the timbers over.

Concrete crib walls. An interesting alternative to wood comes in the form of precast concrete "logs" with indentations at each end that make them closely resemble the Lincoln log toys of another generation. The logs can be assembled quickly in a crib configuration and tilled with gravel or stone. Precast Inc. (P.O. Box 1, Gray, ME 04039) supplies this product in the New England area.

Gabions. Wire baskets filled with stones, stacked on top of each other, are not the first thing that might pop into one's mind, but not a bad idea on second thought. In fact, this is a system that has been around a long time, first gaining popularity in Europe. The rectangular wire mesh compartmental containers are usually 3 feet wide and 1 to 3 feet high, coming in varying lengths. In a labor intensive installation, they are stacked and hand filled with stone or cobbles on the order of 4 to 8 inches in size.

Like most other crib-type structures,

Glossary of Retaining-Wall Terms

Friction Angle: A property of a soil related to the friction developed between individual grains. Essentially, it is the angle of repose—the angle a dry pile of soil will assume with the horizontal.

Frost-Active Soil: A soil containing enough silt particles (usually 5 or 6 percent by weight of the soil) to make it a likely candidate for frost heave. Material passing a #200 sieve is usually defined as silt in this context.

Hydrostatic Pressure: At a point 5 feet below the water's surface, the fluid or hydrostatic pressure is 5 times 62.4 (the weight of a cubic foot of water), or 312 pounds per square foot in all directions.

Lateral Pressure Coefficient (k): The number you multiply by the vertical pressure (weight) of the soil to get its horizontal pressure against a wall. The value of k decreases as the soil's friction angle increases. For a typical sand, $k = 1/3$.

Moment: The same as torque—the type of force a wrench applies about a bolt. A horizontal force against a wall applies a moment about the toe called the overturning moment.

Zone of Failure: The area behind a retaining wall subject to collapse. Its angle with the horizontal equals 45 degrees plus half the soil's friction angle.



This timber crib wall (top) leans dangerously under the surcharge from the autos above. More timbers tied into the upper slope might have helped. A similar structure (bottom) uses concrete "logs" to successfully form earth-holding cribs.



Precast, Inc.



Dry stone walls (top) should be wide at the bottom and have a slope or "better" into the hillside. The taller stone structure (bottom) is actually a type of crib wall called a gabion. Gabions are made by stacking stone-filled wire baskets. They offer good drainage and can tolerate frost heave.



Maccaferri Gabions, Inc.

gabions offer flexibility, a unique appearance, good drainage and, significantly, they may not need to be founded below the normal frost depth. While a cast-in-place concrete wall would develop major cracks if allowed to frost heave, these structures are usually flexible enough to accommodate frost movement without undesirable effects.

One manufacturer of a gabion container systems is Maccaferri Gabion, Inc., (Bldg. C. 210 Summit Avenue, Montvale, NJ 07645).

Precast concrete blocks. Large, precast hollow concrete blocks that interlock offer an easily constructed modular gravity-wall system. These blocks, filled with gravel for added weight, are sized for higher walls, although there's probably no reason a single course or two could not make an attractive low wall.

Doublewall Corporation (Seven West Main St., Plainville, CT, 06062) produces this type of system in New England.

Also, a number of concrete suppliers now dispose of extra concrete from returning mixers in forms that produce blocks on the order of 4x4x2 feet or 4x2x2 feet. The end result may have some uneven top surfaces, a few honeycombs and an occasional cold joint—but it is a solid concrete block and it is usually inexpensive. These blocks can be stacked or placed in a running bond pattern to form a low wall that may be the most economical of all—although by far not the most attractive.

Stone walls. A dry-laid stone wall can be a major architectural component in some types of development. The glaciers generously left behind an endless supply of rounded field stones in the Northeast, and stone walls add a definite regional touch in a part of the country where walls and fences were once routinely made of stone.

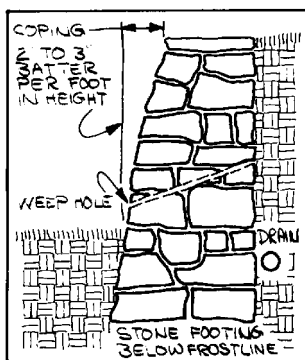


Figure 4. Dry stone wall. A dry-laid wall should be as wide at its base as half the height and the face should be "battered" back by 2 or 3 inches for every foot of height. Well-draining backfill, and good drainage are also very important.

A stone wall gets its stability from both gravity and the friction developed between the stones. In general, the width of the wall at its base should be half the height. It is also a good idea to slope, or "batter," the exposed face back toward the uphill side. Make the slope 2 or 3 inches per foot of height.

Stone walls, because they rely only on friction for internal strength, are especially vulnerable to lateral movement. It is not uncommon to see a wall built with a positive batter leaning in the other direction after a few seasons of frost action. Thus, it is very important to backfill these structures with "clean," well-draining, non-frost-susceptible material.

Since the lateral pressure against the wall any depth is the lateral pressure coefficient (k) times the depth times the unit weight of the soil, it pays to choose a backfill with low unit weight and a high friction angle (k decreases as the friction angle increases). With that in mind, a one-sized crushed stone (say 1/2- or 3/4-inch) fits the bill nicely. Such a stone might have a unit weight of 100 pounds per cubic foot (pcf) as opposed to a well-graded gravel, which might weigh in at 130 to 135 pcf. A fine sand would have a low unit weight (roughly 100 pcf), but a lower friction angle than either stone or gravel.

An added benefit to the stone is high permeability, which insures no build-up of water pressure in the material behind the wall, assuming the wall also contains void spaces—or weep holes if it is a mortared wall.

Saving a Leaning Wall

Once a wall starts to fail, usually by a progressively increasing list to the downhill side, the question of salvaging it arises. First one has to decide whether the wall section is basically sound and stable or not.

If it is reasonably sound, a successful repair may be feasible. The choices center around decreasing the acting forces (water and soil pressure, frost action, height of backfill) on the one hand, and adding structural support on the other.

In the former category, it may make sense to replace the material behind the wall, especially if there is good evidence to indicate the existing backfill is impermeable and frost active. Now it really becomes important to use a low-unit-weight replacement backfill to reduce that soil pressure.

The best backfill of all (and most expensive, by far) is lightweight aggregate, an expanded shale commonly used for aggregate in lightweight concrete. This material, in the 1/2- to 3/4-inch size range, will have a unit weight on the order of 50 pcf, about half that of sand or crushed stone. Two suppliers in New England are Norlite Corporation (628 South Saratoga Street, Cohoes, NY 12047) and Solite (P.O. Box 539, West New York, NJ 07093).

Additional structural support of a wall usually takes the form of buttressing on the downhill side, perpendicular to the face of the wall. This can be done quite effectively with concrete walls, assuming there's space available. If that's not the case, steel tie rods can be used to anchor the wall to driven piles or concrete deadmen in the area behind the wall, as shown earlier in Figure 3.

Safety

Finally, a word about safety—in the form of guard rails. The BOCA Basic Building Code states that when walls retaining more than 4 feet of grade difference are located "closer than 2 feet to a walk, path, parking lot, or driveway on the high side," a 42-inch-high guard rail must be provided. It is generally accepted that longitudinal rails or vertical balusters should be spaced to allow 6-inch maximum openings.

Certainly, it never hurts to be conservative in this regard. Even if a guard is not warranted, adequate safeguards should exist to protect the unwary pedestrian—from printed warnings to landscaping that discourages people from getting near the top of the wall. ■

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