CHAPTER 6

Concepts of Soil Engineering

The military engineer encounters a wide variety of soils in varying physical states. Because of the inherent variability of the physical properties of soil, several tests and measurements within soils engineering were developed to quantify these differences and to enable the engineer to apply the knowledge to economical design and construction. This chapter deals with soil engineering concepts, to include settlement, shearing resistance, and bearing capacity, and their application in the military construction arena.

Section I. Settlement

FACTORS

The magnitude of a soil's settlement depends on several factors, including—

- Density.
- Void ratio.
- Grain size and shape.
- Structure.
- Past loading history of the soil deposit.
- Magnitude and method of application of the load.
- Degree of confinement of the soil mass.

Unless otherwise stated, it is assumed that the soil mass undergoing settlement is completely confined, generally by the soil that surrounds it.

COMPRESSIBILIY

Compressibility is the property of a soil that permits it to deform under the action of an external compressive load. Loads discussed in this chapter are primarily static loads that act, or may be assumed to act, vertically downward. Brief mention will be made of the effects of vibration in causing compression. The principal concern here is with the property of a soil that permits a reduction in thickness (volume) under a load like that applied by the weight of a highway or airfield. The compressibility of the underlying soil may lead to the settlement of such a structure.

Compressive Load Behavior

In a general sense, all soils are compressible. That is, they undergo a greater or lesser reduction in volume under compressive static loads. This reduction in volume is attributed to a reduction in volume of the void spaces in the soil rather than to any reduction in size of the individual soil particles or water contained in the voids.

If the soil is saturated before the load is applied, some water must be forced from the voids before settlement can take place. This process is called consolidation. The rate of consolidation depends on how quickly the water can escape, which is a function Of the soil's permeability.

Cohesionless Soils

The compressibility of confined coarse-grained cohesionless soils, such as sand and gravel, is rarely a practical concern. This is because the amount of compression is likely to be small in a typical case, and any settlement will occur rapidly after the load is applied. Where these soils are located below the water table, water must be able to escape from the stratum. In the case of coarse materials existing above the water table and under less than saturated conditions, the application of a static load results in the rearrangement of soil particles. This produces deformation without regard to moisture escape. So, generally speaking, settlement occurs during the period of load application (construction). Deformations that are thus produced in sands and gravels are essentially permanent in character. There is little tendency for the soil to return to its original dimensions or rebound when the load is removed. A sand mass in a compact condition may eventually attain some degree of elasticity with repeated applications of load.

The compressibility of a loose sand deposit is much greater than that of the same sand in a relatively dense condition. Generally, structures should not be located on loose sand deposits. Avoid loose sand deposits if possible, or compact to a greater density before the load is applied. Some cohesionless soils, including certain very fine sands and silts, have loose structures with medium settlement characteristics. Both gradation and grain shape influence the compressibility of a cohesionless soil. Gradation is of indirect importance in that a well-graded soil generally has a greater natural density than one of uniform gradation. Soils that contain platy particles are more compressible than those composed entirely of bulky grains. A fine sand or silt that contains mica flakes maybe quite compressible.

Although soils under static loads are emphasized here, the effects of vibration should also be mentioned. Vibration during construction may greatly increase the density of cohesionless soils. A loose sand deposit subjected to vibration after construction may also change to a dense condition. The latter change in density may have disastrous effects on the structures involved. Cohesionless soils are usually compacted or "densified" as a planned part of construction operations. Cohesive soils are usually insensitive to the effects of vibrations.

CONSOLIDATION

Consolidation is the time-dependent change in volume of a soil mass under compressive load that occurs when water slowly escapes from the pores or voids of the soil. The soil skeleton is unable to support the load and changes structure, reducing its volume and producing vertical settlement.

Cohesive Soils

The consolidation of cohesive, fine-grained soils (particularly clays) is quite different from the compression of cohesionless soils. Under comparable static loads, the consolidation of a clay may be much greater than coarse-grained soils and settlement may take a very long time to occur. Structures often settle due to consolidation of a saturated clay stratum. The consolidation of thick, compressible clay layers is serious and may cause structural damage. In uniform settlement, the various parts of a structure settle approximately equal amounts. Such uniform settlement may not be critical. Nonuniform, or differential, settlement of parts of a structure due to consolidation causes serious structural damage. A highway or airfield pavement may be badly damaged by the nonuniform settlement of an embankment founded on a compressible soil.

Consolidation Tests

The consolidation characteristics of a compressible soil should be determined for rational design of many large structures founded on or above soils of this type. Consolidation characteristics generally are determined by laboratory consolidation tests performed on undisturbed samples. The natural structure, void ratio, and moisture content are preserved as carefully as possible for undisturbed samples. However, military soils analysts are not equipped or trained to perform consolidation tests.

Information on consolidation tests and settlement calculations for the design of structures to be built on compressible soils may be found in Naval Facilities Engineering Command Design Manual *(NAVFAC DM)-7.1.*

Section II. Shearing Resistance

IMPORTANCE

From an engineering viewpoint, one of the most important properties a soil possesses is shearing resistance or shear strength. A soil's shearing resistance under given conditions is related to its ability to withstand loads. The shearing resistance is especially important in its relation to the supporting strength, or bearing capacity, of a soil used as abase or subgrade beneath a road, runway, or other structure. The shearing resistance is also important in determining the stability of the slopes used in a highway or airfield cut or embankment and in estimating the pressures exerted against an earth-retaining structure, such as a retaining wall.

LABORATORY TESTS

Three test procedures are commonly used in soil mechanics laboratories to determine the shear strength of a soil. These are—

- Direct shear test.
- Triaxial compression test.
- Unconfined compression test.

The basic principles involved in each of these tests are illustrated in the simplified drawings of *Figure 6-1.* Military soils analysts are not equipped or trained to perform the direct shear or triaxial compression tests. For most military applications, the CBR value of a soil is used as a measure of shear strength (see *TM 5-530).*

A variation of the unconfined compression test can be performed by military soils analysts, but the results are ordinarily used only in evaluation of soil stabilization. Shear

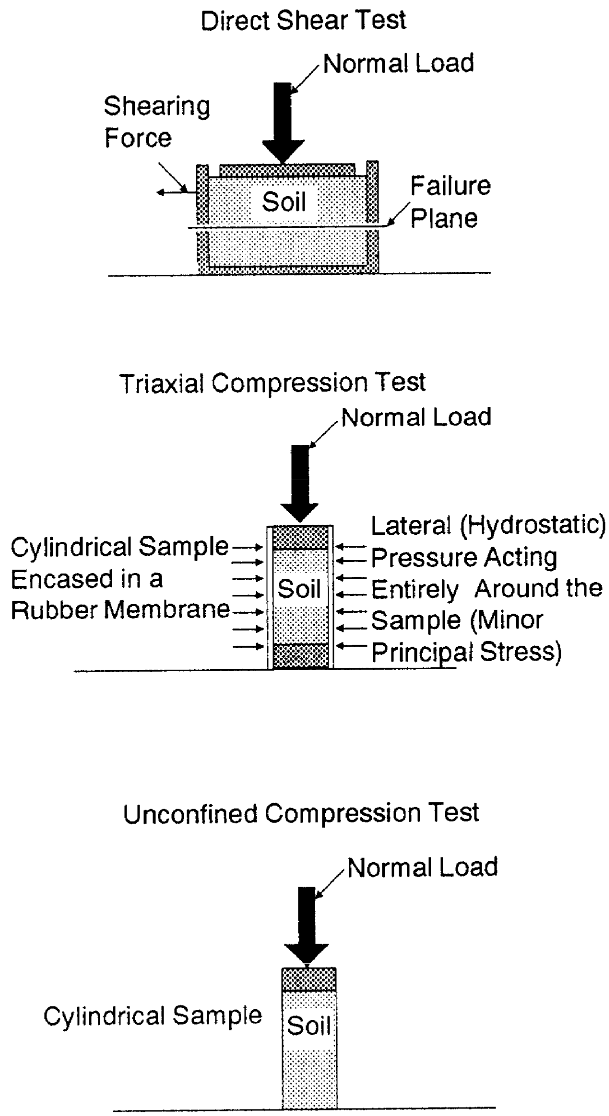


Figure 6-1. Laboratory shear tests.

strength for a soil is expressed as a combination of an apparent internal angle of friction (normally associated with cohesive soils).

CALIFORNIA BEARING RATIO

The CBR is a measure of the shearing resistance of a soil under carefully controlled conditions of density and moisture. The CBR is determined by a penetration shear test and is used with empirical curves for designing flexible pavements. Recommended design procedures for flexible pavements are presented in *TM 5-330*. The CBR test procedure for use in design consists of the following steps:

- Prepare soil test specimens.
- Perform penetration test on the prepared soil samples.
- Perform swell test on soil test specimens.

Although a standardized procedure has been established for the penetration portion of the test, one standard procedure for the preparation of test specimens cannot be established because soil conditions and construction methods vary widely. The soil test specimen is compacted so it duplicates as nearly as possible the soil conditions in the field.

In a desert environment, soil maybe compacted and tested almost completely dry. In a wet area, soil should probably be tested at 100 percent saturation. Although penetration tests are most frequently performed on laboratory-compacted test specimens, they may also be performed on undisturbed soil samples or on in-place soil in the field. Detailed procedures for conducting CBR tests and analyzing the data are in *TM 5-330*. *Appendix A* describes the procedure for applying CBR test data in designing roads and airfields.

Column 15, *Table 5-3, page 5-11,* shows typical ranges in value of the field CBR for soils in the USCS. Values of the field CBR may range from as low as 3 for highly plastic, inorganic clays (CH) and some organic clays and silts (OH) to as high as 80 for well-graded gravel and gravel-sand mixtures.

AIRFIELD INDEX (AI)

Engineering personnel use the airfield cone penetrometer to determine an index of soil strengths (called Airfield Index) for various military applications.

Airfield Cone Penetrometer

The airfield cone penetrometer is compact, sturdy, and simple enough to be used by military personnel inexperienced in soil strength determination. If used correctly, it can serve as an aid in maintaining field control during construction operations; however, this use is not recommended, because more accurate methods are available for use during construction.

Description. The airfield cone penetrometer is a probe-type instrument consisting of a right circular cone with a base diameter of 1/2 inch mounted on a graduated staff. On the opposite end of the staff are a spring, a load indicator, and a handle. The overall length of the assembled penetrometer is 36 1/8 inches. For ease in carrying, the penetrometer can be disassembled into three main pieces. They are—

- Two extension staffs, each 12 5/8 inches long.
- One piece 14 3/4 inches long containing the cone, handle, spring, and load indicator.

The airfield cone penetrometer has a range of zero to 15.

The airfield cone penetrometer must not be confused with the trafficability penetrometer, a standard military item included in the Soil Test Set. The cone penetrometer used for trafficability has a dial-type load indicator (zero to 300 range) and is equipped with a cone 1/2 inch in diameter and a cross-sectional area of 0.2 square inch and another cone 0.8 inch in diameter and a cross-sectional area of 0.5 square inch. If the trafficability penetrometer is used to measure the AI, the readings obtained with the 0.2-square-inch cone must be divided by 20; the reading obtained with the 0.5-square-inch cone must be divided by 50.

Operation. Before the penetrometer is used, inspect the instrument to see that all joints are tight and that the load indicator reads zero. To operate the penetrometer, place your palms down symmetrically on the handle. Steady your arms against your thighs and apply force to the handle until a slow, steady, downward movement of the instrument occurs. Read the load indicator at the moment the base of the cone enters the ground (surface reading) and at desired depths at the moment the corresponding depth mark on the shaft reaches the soil surface. The reading is made by shifting the line of vision from the soil surface to the indicator just a moment before the desired depth is reached. Maximum efficiency is obtained with a two-person team in which one person operates and reads the instrument while the other acts as a recorder. One person can operate the instrument and record the measurements by stopping the penetration at any intermediate depth, recording previous readings, and then resuming penetration. Observe the following rules to obtain accurate data:

- Make sure the instrument reads zero when suspended by the handle and 15 when a 150-pound load is applied.
- Keep the instrument in a vertical position while it is in use.
- Control the rate of penetration at about 1/2 to 1 inch per second. (Slightly faster or slower rates will not materially affect the readings, however.)
- If you suspect the cone is encountering a stone or other foreign body at the depth where a reading is desired, make another penetration nearby.
- Take readings at the proper depths. (Carelessness in determining depth is one significant source of error in the use of the penetrometer.)

Maintenance. The airfield cone penetrometer is simply constructed of durable metals and needs little care other than cleaning and oiling. The calibration should be checked occasionally. If an error in excess of about 5 percent is noted, recalibrate the penetrometer.

Soil-Strength Evaluation

The number of measurements to be made, the location of the measurements, and other such details vary with each area to be examined and with the time available. For this reason, hard and fast rules for evaluating an airfield are not practical, but the following instructions are useful:

Fine-Grained Soils. A reading near zero can occur in a very wet soil; it cannot support traffic. A reading approaching 15 occurs in dry, compact clays or silts and tightly packed sands or gravels. Most aircraft that might be required to use an unpaved area could easily be supported for a substantial number of landing and takeoffs on a soil having an AI of 15.

Soil conditions are extremely variable. As many penetrometer measurements should be taken as time and circumstances permit. The strength range and uniformity of an area controls the number of measurements necessary. Areas obviously too soft for emergency landing strips will be indicated after a few measurements, as will areas with strengths that are more than adequate. In all areas, the spots that appear to be softest should be tested first, since the softest condition of an area controls suitability. Soft spots are not always readily apparent. If the first test results indicate barely adequate strength, the entire area should be examined. Penetrations in areas that appear to be firm and uniform may be few and widely spaced, perhaps every 50 feet along the proposed centerline. In areas of doubtful strength, the penetrations should be more closely spaced, and areas on both sides of the centerline should be investigated. No fewer than three penetrations should be made at each location and usually five are desirable. If time permits, or if inconsistencies are apparent, as many as 10 penetrations should be made at each test location.

Soil strength usually increases with depth; but in some cases, a soil has a thin, hard crust over a deep, soft layer or has thin layers of hard and soft material. For this reason, each penetration should be made to a 24-inch depth unless prevented by a very firm condition at a lesser depth. When penetration cannot be made to the full 24-inch depth, a hole should be dug or augured through the firm materials, and penetrometer readings should be taken in the bottom of the hole to ensure that no soft layer underlies the firm layer. If possible, readings should be taken every 2 inches from the surface to a depth of 24 inches. Generally, the surface reading should be disregarded when figures are averaged to obtain a representative AI.

In the normal soil condition, where strength increases with depth, the readings at the 2- to 8-inch depths (4 to 10 inches for dry sands and for larger aircraft) should be used to designate the soil strength for airfield evaluation. If readings in this critical layer at any one test location do not differ more than 3 or 4 units, the arithmetic average of these readings can be taken as the AI for the areas represented by the readings. When the range between the highest and lowest readings is more than about 4, the engineer must use judgment in arriving at a rating figure. For conservatism, the engineer should lean toward the low readings.

In an area in which hard crust less than about 4 inches thick overlies a much softer soil, the readings in the crust should not be used in evaluating the airfield. For example, if a 3-inch-thick crust shows average readings of 10 at the 2-inch depth and average readings of 5 below 3 inches, the area should be evaluated at 5. If the crust is more than about 4 inches thick, it will probably play an important part in aircraft support. If the crust in the above instance is 5 inches thick, the rating of the field would then be about halfway between the 10 of the crust and the 5 of the underlying soil or, conservatively, 7. Innumerable combinations of crust thickness and strength and underlying soil strength can occur. Sound reasoning and engineering judgment should be used in evaluating such areas.

In an area in which a very soft, thin layer is underlain by a firmer layer, the evaluation also is a matter of judgment. If, for example, there are 1 to 2 inches of soil with an index averaging about 5 overlying a soil with an index of 10, rate the field at 10; but if this soft layer is more than about 4 inches thick, rate the field at 5. Areas of fine-grained soils with very low readings in the top 1 inch or more are likely to be slippery or sticky, especially if the soil is a clay.

Coarse-Grained Soils. When relatively dry, many sands show increasing AIs with depth, but the 2-inch depth index will often be low, perhaps about 3 or 4, Such sands usually are capable of supporting aircraft that require a much higher AI than 3 to 4, because the strength of the sand actually increases under the confining action of the aircraft tires. Generally, any dry sand or gravel is adequate for aircraft in the C-130 class, regardless of the penetrometer readings. All sands and gravel in a “quick” condition (water moving upward through them) must he avoided. Evaluation of wet sands should be based on the penetrometer readings obtained as described earlier.

Once the strength of the soil, in terms of AI, has been established by use of the airfield cone penetrometer, the load-carrying capability of this soil can be determined for each kind of forward, support, or rear-area airfield through use of the subgrade strength requirements curves. These curves are based on correlations of aircraft performance and AIs. Unfortunately, these are not exact correlations uniquely relating aircraft performance to AI. As soils vary in type and condition from site to site, so varies the relation of AI to aircraft performance. For this reason, the curves may not accurately reflect performance in all cases. These relations were selected so that in nearly all cases aircraft performance will be equal to or better than that indicated.

CORRELATION BETWEEN CBR AND Al

Expedient soil strength measurements in this manual are treated in terms of AI. Measurement procedures using the airfield penetrometer are explained; however, in the references listed at the end of this manual, which cover less expedient construction methods, soil strength is treated in terms of CBR. To permit translation between the CBR and the AI, a correlation is presented in *Figure 6-2.* This figure can be used for estimating CBR values from AI determinations. This correlation has been established to yield values of CBR that generally are conservative. The tendency toward conservatism is necessary because there is no unique relationship between these measurements over a wide range of soil types. It follows that

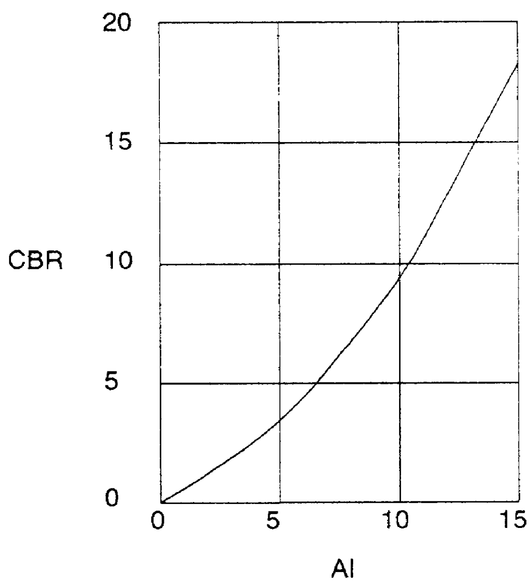


Figure 6-2. Correlation of CBR and AI.

the curve should not be used to estimate AI values from CBR determinations since these would not be conservative.

Section III. Bearing Capacity

IMPORTANCE

The bearing capacity of a soil is its ability to support loads that may be applied to it by an engineering structure, such as—

- A building, a bridge, a highway pavement, or an airport runway and the moving loads that may be carried thereon.
- An embankment.
- Other types of load.

A soil with insufficient bearing capacity to support the loads applied to it may simply fail by shear, allowing the structure to move or sink into the ground. Such a soil may fail because it undergoes excessive deformation, with consequent damage to the structure. Sometimes the ability of a soil to support loads is simply called its stability. Bearing capacity is directly related to the allowable load that may be safely placed on a soil. This allowable load is sometimes called the allowable soil pressure.

Types of failure that may take place when the ultimate bearing capacity is exceeded are illustrated in *Figure 6-3*. Such a failure may involve tipping of the structure, with a bulge at the ground surface on one side of the structure. Failure may also take place on a number of surfaces within the soil, usually accompanied by bulging of the ground around the foundation. The ultimate bearing capacity not only is a function of the nature and condition of the soil involved but also depends on the method of application of the load.

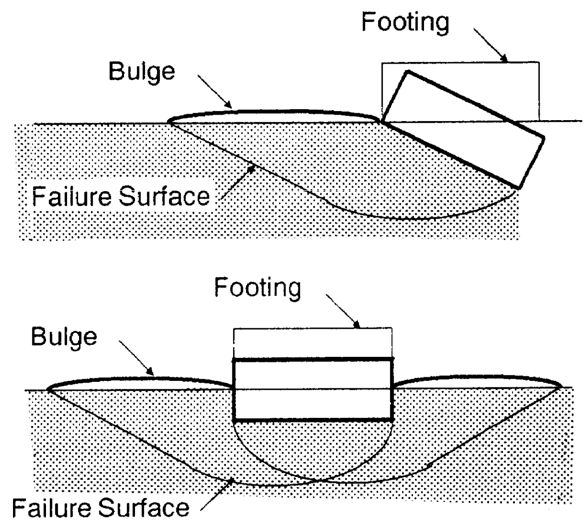


Figure 6-3. Typical failure surfaces beneath shallow foundations.

FOUNDATIONS

The principle function of a foundation is to transmit the weight of a structure and the loads that it carries to the underlying soil or rock. A foundation must be designed to be safe against a shear failure in the underlying soil. This means that the load placed on the soil must not exceed its ultimate bearing capacity.

Shallow Foundations

A shallow foundation is one that is located at, or slightly below, the surface of the ground. A typical foundation of this type is seen in the shallow footings, either of plain or reinforced concrete, which may support a building. Footings are generally square or rectangular. Long continuous or strip footings are also used, particularly beneath basement or retaining walls. Another type of shallow foundation is the raft or mat; it may cover a large area, perhaps the entire area occupied by a structure.

Deep Foundations

When the surface soils at the site of a proposed structure are too weak and compressible to provide adequate support, deep foundations are frequently used to transfer the load to underlying suitable soils. Two common types of deep foundations are—

- Pile.
- Pier.

Piles. Piles and pile foundations are very commonly used in both military and civil construction. By common usage, a pile is a load-bearing member made of timber, concrete, or steel, which is generally forced into the ground. Piles are used in a variety of forms and for a variety of purposes. A pile foundation is one or more piles used to support a pier, or column, or a row of piles under a wall. Piles of this type are normally used to support vertical loads, although they may also be used to support inclined or lateral forces.

Piles driven vertically and used for the direct support of vertical loads are commonly called bearing piles. They may be used to transfer the load through a soft soil to an underlying firm stratum. These are called end-bearing piles. Bearing piles may also be used to distribute the load through relatively soft soils that are not capable of supporting concentrated surface loads. These are called friction piles. A bearing pile may sometimes receive its support from a combination of end bearing and friction. Bearing piles also may be used where a shallow foundation would likely be undetermined by scour, as in the case of bridge piers. Bearing piles are illustrated in *Figure 6-4.*

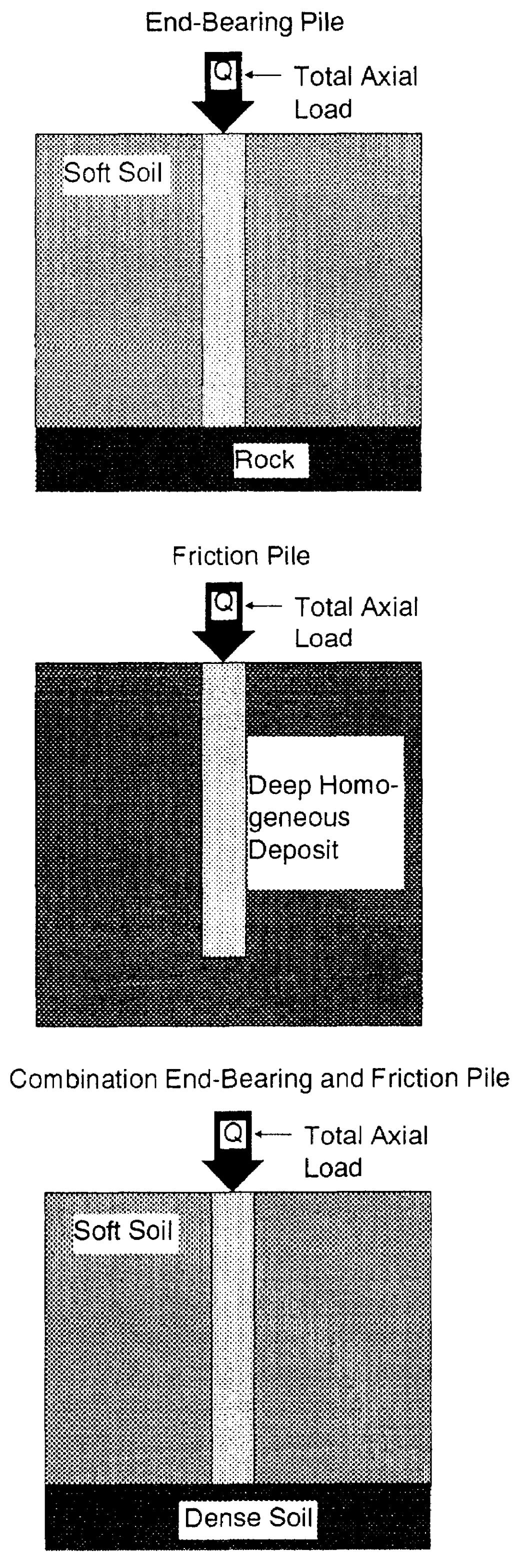


Figure 6-4. Bearing piles.

A typical illustration of an end-bearing pile is when a pile driven through a very soft soil, such as a loose silt or the mud of a river bottom, comes to rest on firm stratum beneath. The firm stratum may, for example, be rock, sand, or gravel. In such cases, the pile derives practically all its support from the underlying firm stratum.

A friction pile develops its load-carrying capacity entirely, or principally, from skin friction along the sides of the pile. The load is transferred to the adjoining soil by friction between the pile and the surrounding soil. The load is thus transferred downward and laterally to the soil. The soil surrounding the pile or group of piles, as well as that beneath the points of the piles, is stressed by the load.

Some piles carry a load by a combination of friction and end bearing. A pile of this sort may pass through a fairly soft soil that provides some frictional resistance; then it may pass into a firm layer that develops load-carrying capacity through a combination of friction over a relatively short length of embedment and end bearing.

Piles are used for many purposes other than support for vertical loads. Piles that are driven at an angle with the vertical are commonly called batter piles. They may be used to support inclined loads or to provide lateral loads. Piles are sometimes used to support lateral loads directly, as in the pile fenders that may be provided along waterfront structures to take the wear and shock of docking ships. Sometimes piles are used to resist upward, tensile forces. These are frequently called anchor piles. Anchor piles may be used, for example, as anchors for bulkheads, retaining walls, or guy wires. Vertical piles are sometimes driven for the purpose of compacting loose cohesionless deposits. Closely spaced piles, or sheet piles, may be driven to form a wall or a bulkhead that restrains a soil mass.

Piers. Piers are much less common than piles and are normally used only for the support of very heavy loads.

Section IV. Earth-Retaining Structures

PURPOSE

Earth-retaining structures must be used to restrain a mass of earth that will not stand unsupported. Such structures are commonly required when a cut is made or when an embankment is formed with slopes too steep to stand alone.

Earth-retaining structures are subjected to lateral thrust from the earth masses that they support. The pressure of the earth on such a structure is commonly called lateral earth pressure. The lateral earth pressure that may be exerted by a given soil on a given structure is a function of many variables. It must be estimated with a reasonable degree of accuracy before an earth-retaining structure may be properly designed. In many cases, the lateral earth pressure may be assumed to be acting in a horizontal direction or nearly so.

TYPES

Earth-retaining structures discussed in this section are retaining walls and bracing systems used in temporary excavations.

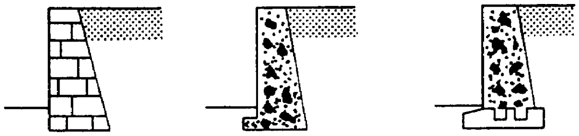
Retaining Walls

A retaining wall is a wall constructed to support a vertical or nearly vertical earth bank that, in turn, may support vertical loads. Generally, retaining walls are classified into the following five types (see *Figure 6-5, page 6-10)*:

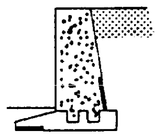
- Gravity.
- Cantilever.
- Counterfort.
- Buttressed.
- Crib.

When a retaining wall is used to support the end of a bridge span, as well as retain the earth backfill, it is called an abutment. There are several types of gravity retaining walls, such as—

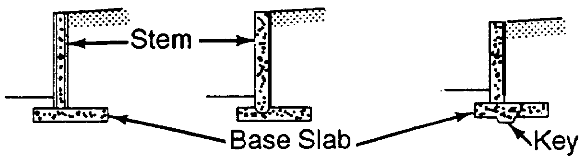
- Timber.
- Plain concrete.



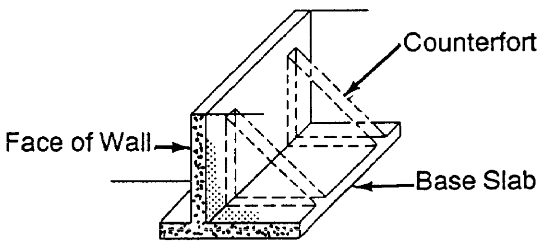
Gravity Walls
Plain concrete or rubble, no tensile stress in any portion of the wall. Rugged construction is conservative but not economical for high walls.



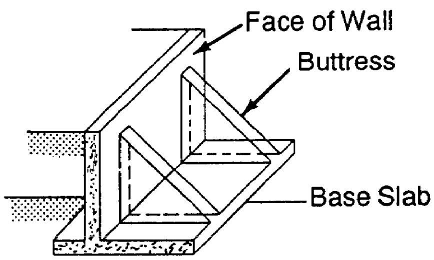
Semigravity Walls
A small amount of reinforcing steel is used for reducing the mass of concrete.



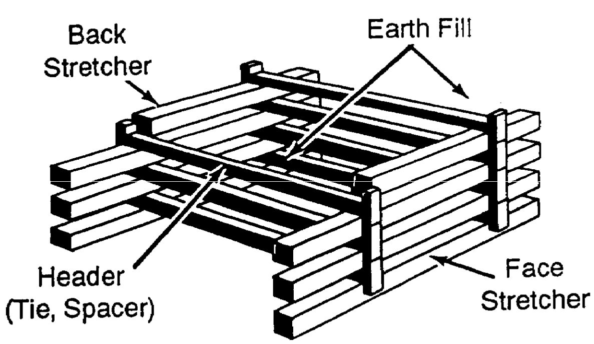
Cantilever Walls
In the form of an inverted T, each projecting portion acts as a cantilever. It is usually made of reinforced concrete. For small walls, reinforced-concrete blocks may be used. This type is economical for walls of small to moderate height (about 20-25 feet).



Counterfort Walls
Both base slab and face of wall span horizontally between vertical brackets known as counterforts. This type is suitable for high retaining walls (greater than about 20 feet).



Buttressed Walls
Similar to the counterfoil wall except that the backfill is on the opposite side of the vertical brackets known as buttresses. Not commonly used because of the exposed buttresses.



Crib Walls
Formed by timber, precast concrete, or prefabricated steel members and filled with granular soil. This type is suitable for walls of small to moderate height (about 21 feet maximum) subjected to moderate earth pressure. No surcharge load except earth fill should be placed directly above the crib wall.

Figure 6-5. Principal types of retaining walls.

- Sheet piling.
- Rubble.
- Stone or brick masonry.
- Crib.
- Gabions.

Retaining walls are used in many applications. For example, a structure of this sort may be used in a highway or railroad cut to permit the use of a steep slope and avoid excessive amounts of excavation. Retaining walls are similarly used on the embankment side of sidehill sections to avoid excessive volumes of fill. Bridge abutments and the headwalls of culverts frequently function as retaining walls. In the construction of buildings and various industrial structures, retaining walls are often used to provide support for the side of deep, permanent excavations.

Permanent retaining walls are generally constructed from plain or reinforced concrete; stone masonry walls are also used occasionally. In military construction, timber crib retaining walls are important. Their design is discussed later.

Backfills. The design of the backfill for a retaining wall is as important as the design of the wall itself. The backfill must be materials that are—

- Reasonably clean.
- Granular.
- Essentially cohesionless.
- Easily drained.
- Not susceptible to frost action.

The best materials for backfills behind retaining walls are clean sands, gravels, and crushed rock. In the USCS, the (GW) and (SW) soils are preferred, if they are available. The (GP) and (SP) soils are also satisfactory. These granular materials require compaction to make them stable against the effects of vibration. Compaction also generally increases the angle of internal friction, which is desirable in that it decreases the lateral pressure exerted on the wall. Materials of the (GM), (GC), (SM), and (SC) groups maybe used for backfills behind retaining walls, but they must be protected against frost action and may require elaborate drainage provisions. Fine- grained soils are not desirable as backfills because they are difficult to drain. If clay soil must be used, the wall should be designed to resist earth pressures at rest. Ideal backfill materials are purely granular soils containing < 5 percent of fines.

Backfills behind retaining walls are commonly put in place after the structure has been built. The method of compaction depends on the—

- Soil.
- Equipment available.
- Working space.

Since most backfills are essentially cohesionless, they are best compacted by vibration. Equipment suitable for use with these soils is discussed in *Chapter 8*. Common practice calls for the backfill to be placed in layers of loose material that, when compacted, results in a compacted layer thickness of from 6 to 8 inches. Each layer is compacted to a satisfactory density. In areas inaccessible to rollers or similar compacting equipment, compaction may be done by the use of mechanical air tampers or hand tools.

Drainage. Drainage of the backfill is essential to keep the wall from being subjected to water pressure and to prevent frost action. Common drainage provisions used on concrete walls are shown in *Figure* 6-6, *page 6-12*.

When the backfill is composed of clean, easily drained materials, it is customary to provide for drainage by making weep holes through the wall. Weep holes are commonly made by embedding pipes 4 to 6 inches in diameter into the wall. These holes are spaced from 5 to 10 feet center to center both horizontally and vertically. A filter of granular material should be provided around the entrance to each weep hole to prevent the soil from washing out or the drain from becoming clogged. If possible, this material should conform to the requirements previously given for filter materials.

Weep holes have the disadvantage of discharging the water that seeps through the backfill at the toe of the wall where the soil pressures are greatest. The water may weaken the soil at this point and cause the wall to fail. A more effective solution, which is also more expensive, is to provide a longitudinal back drain along the base of the wall (see *Figure 6-6).* A regular pipe drain should be used, surrounded with a suitable filter material. The drainage may be discharged away from the ends of the wall.

If a granular soil, which contains considerable fine material and is poorly drained (such as an (SC) soil) is used in the backfill, then more elaborate provisions may be installed to ensure drainage. One such approach is to use a drainage blanket (see *Figure 6-6).* If

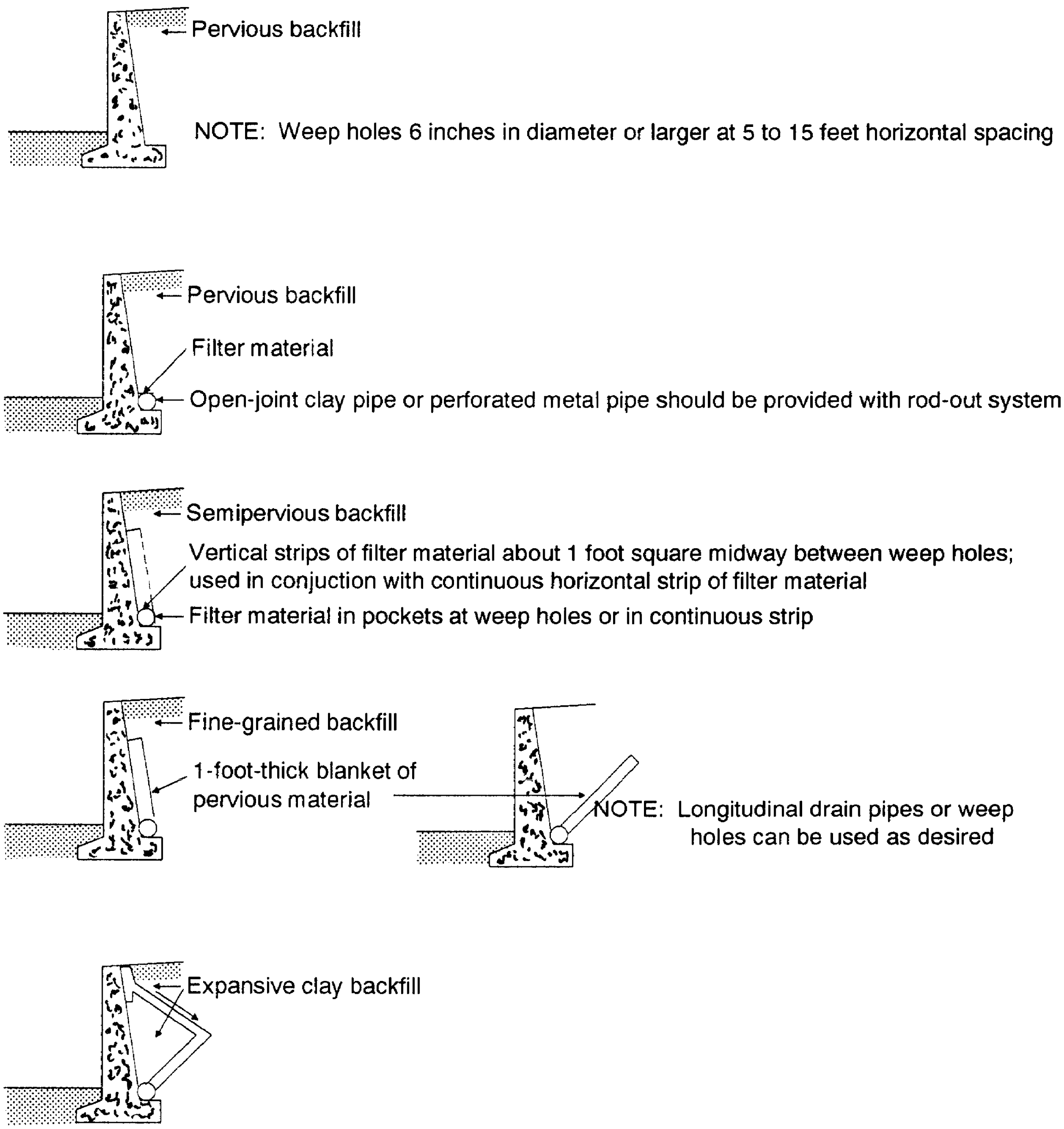


Figure 6-6. Common types of retaining-wall drainage.

necessary, a blanket of impervious soil or bituminous material may be used on top of the backfill to prevent water from entering the fill from the top. Such treatments are relatively expensive.

Frost Action. Conditions for detrimental frost action on retaining walls include the following:

- A frost-susceptible soil.
- Availability of water.
- Freezing temperatures.

If these conditions are present in the backfill, steps must be taken to prevent the formation of ice lenses and the resultant severe lateral pressures that may be exerted against the wall. The usual way to prevent frost action is to substitute a thick layer of clean, granular, nonfrost-susceptible soil for the backfill material immediately adjacent to the wall. The width of the layer should be as great as the maximum depth of frost penetration in the area (see *Figure 6-7).* As with other structures, the bottom of a retaining wall should be located beneath the line of frost penetration.

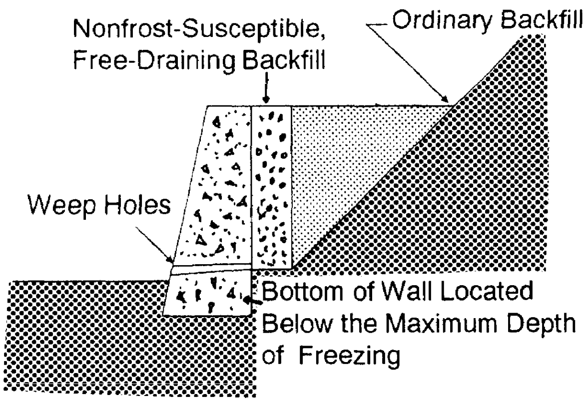


Figure 6-7. Eliminating frost action behind retaining walls.

Timber Crib. A very useful type of retaining wall for military purposes in a theater of operations is timber cribbing. The crib, or cells, are filled with earth, preferably clean, coarse, granular material. A wall of this sort gains its stability through the weight of the material used to fill the cells, along with the weight of the crib units themselves. The longitudinal member in a timber crib is called a stretcher, while a transverse member is a header.

A principal advantage of a timber crib retaining wall is that it may be constructed with unskilled labor and a minimum of equipment. Suitable timber is available in many military situations. Little foundation excavation is usually required and may be limited to shallow trenching for the lower part of the crib walls. The crib maybe built in short sections, one or two cribs at a time. Where the amount of excavation is sufficient and suitable, the excavated soil may be used for filling the cells.

A crib of this sort maybe used on foundation soils that are weak and might not be able to support a heavy wall, since the crib is fairly flexible and able to undergo some settlement and shifting without distress. However, this should not be misunderstood, as the foundation soil must not be so soft as to permit excessive differential settlement that would destroy the alignment of the crib.

Experience indicates that a satisfactory design will generally be achieved if the base width is a minimum of 4 feet at the top and bottom or 50 percent of the height of the wall, provided that the wail does not carry a surcharge and is on a reasonably firm foundation. If the wall carries a heavy surcharge, the base width should be increased to a minimum of 65 percent of the height. In any case, the width of the crib at the top and bottom should not be less than 4 feet.

Timber crib walls may be built with any desired batter (receding upward slope) or even vertical. The batter most often used and recommended is one horizontal to four vertical (see *Figure 6-8, page 6-14).* If less batter is used, the base width must be increased to ensure that the resultant pressure falls within the middle third of the base. The desired batter is normally achieved by placing the base on a slope equal to the batter. The toe maybe placed on sills; this is frequently done with high walls. Sometimes double-cell construction is used to obtain the necessary base width of high walls. The wall is then decreased in width, or "stepped-back," in the upper portions of the wall, above one third height. Additional rows of bottom stretchers

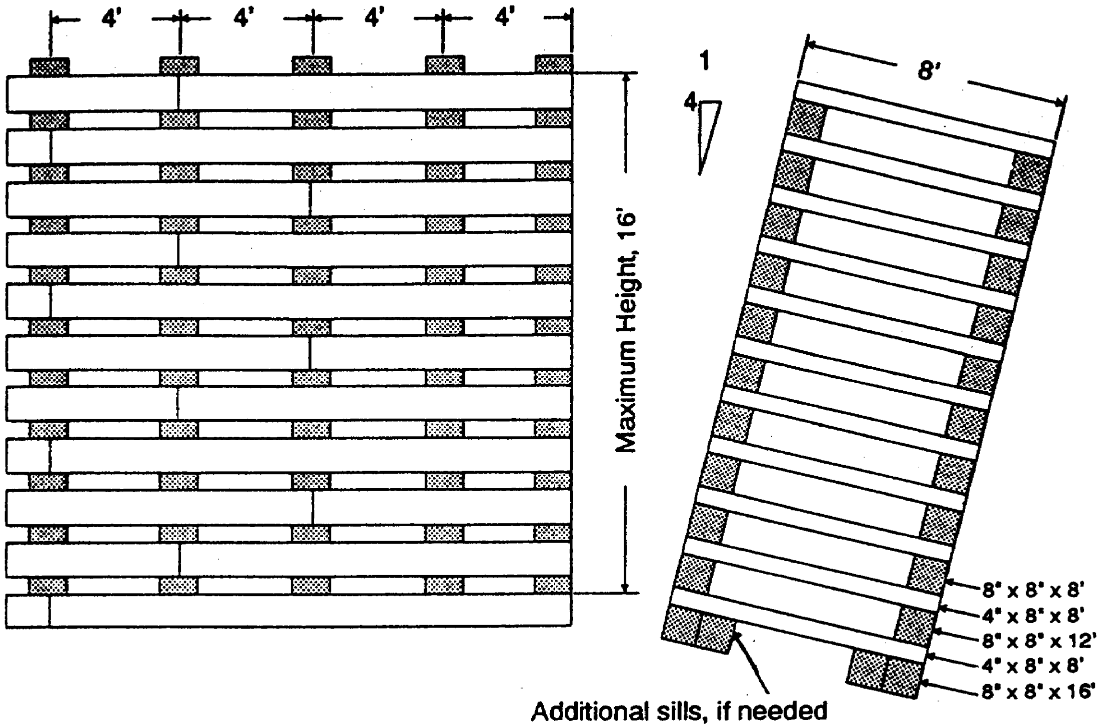


Figure 6-8. Typical timber crib retaining wall.

may be used to decrease the pressure on the soil or to avoid detrimental settlement.

The front and rear wall of the crib should be connected at each panel point. The crib must be kept an essentially flexible structure and must be free to move somewhat in any direction, so as to adjust itself to thrusts and settlements.

The material used in filling the cells should be placed in thin layers and should be well compacted. Backfill behind the wall should also be compacted and kept close to, but not above, the level of the material in the cribs. Drainage behind timber crib walls may or may not be required, depending on local conditions and wall construction.

Figure 6-8 shows the elevation and cross section of a timber crib retaining wall, which may be used to a maximum height of about 16 feet. A similar arrangement maybe used for heights up to about 8 feet, with a minimum width of 4 feet. For heights above 16 feet, the headers are usually 6-inch by 12-inch timbers and the stretchers 12-inch by 12-inch timbers. Timbers are normally connected by means of heavy (3/4-inch diameter) driftpins.

Other Timber Walls. Other types of timber retaining walls are used for low heights, particularly in connection with culverts and bridges. A wall of this sort maybe built by driving timber posts into the ground and attaching planks or logs. Details on retaining walls, used in conjunction with bridge abutments, are given in *TM 5-312. Figure 6-9* illustrates two other types of timber retaining walls.

Gabions. Gabions are large, steel-wire-mesh baskets usually rectangular in shape and variable in size (see *Figure 6-10).* They are designed to solve the problem of erosion at a low cost. Gabions were used in sixteenth century fortifications, and experience in construction with factory-produced prefabricated gabions dates back to 1894 in Italy. Gabions have been wideiy used in Europe and are now becoming accepted in the United States as a valuable and practical construction tool. They can be used in place of sheet piling, masonry construction, or cribbing. Gabions maybe used as—

- Protective and antierosion structures on rivers (as revetments, groynes, or spurs).
- Channel linings.
- Seashore protection.
- Retaining walls for roads or railroads.
- Antierosion structures (such as weirs, drop structures, and check dams).
- Low-water bridges or fords.
- Culvert headwall and outlet structures.
- Bridge abutments and wing walls.

The best use of gabions as retaining walls is where flexibility and permeability are important considerations, especially where unstable ground and drainage conditions impose problems difficult to solve with rigid and impervious material. Use of gabions does require ready access to large-size stones, such as those found in mountainous areas. Areas that are prone to landslides have used gabions successfully. Gabion walls have been erected in mountainous country to trap falling rocks and debris and in some areas to act as longitudinal drainage collectors.

The best filling material for a gabion is one that allows flexibility in the structure but also fills the gabion compartments with the minimum of voids and with the maximum weight. Ideally, the stone should be small, just slightly larger than the size of the mesh. The stone must be clean, hard, and durable to withstand abrasion and resistance to weathering and frost action. The gabions are filled in three lifts, one foot at a time. Rounded stone, if available, reduces the possibility of damage to the wire during mechanical filling as compared with sharp quarry stone. If stone is not available, gabions can be filled with a good quality soil. To hold soil, hardware cloth inserts must be placed inside the gabions. For use in gabions, backfill material should meet

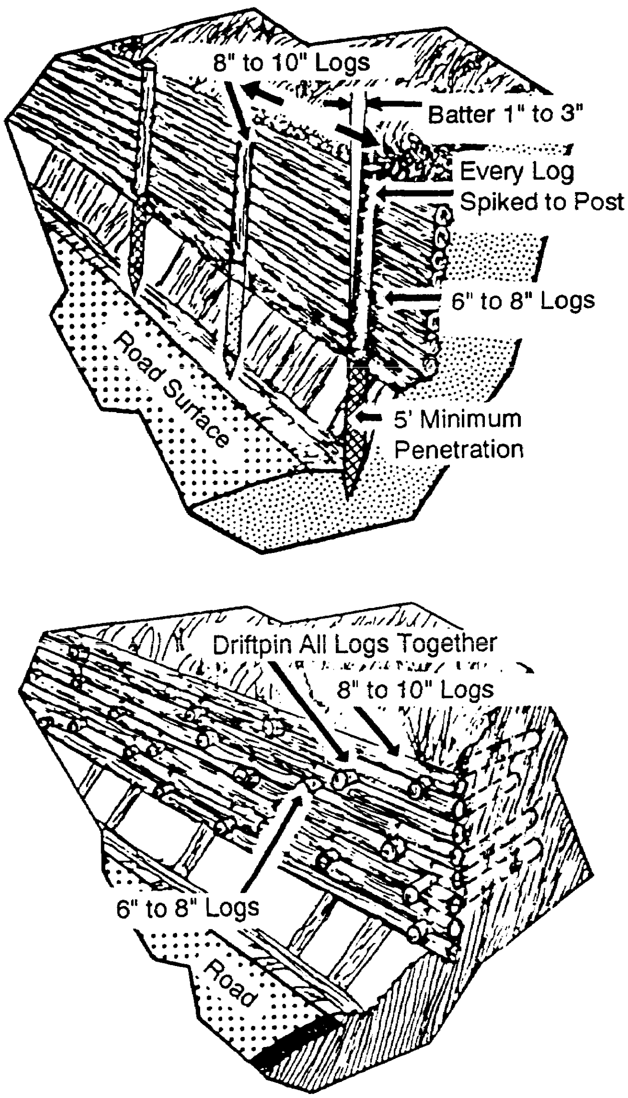


Figure 6-9. Other timber retaining walls.

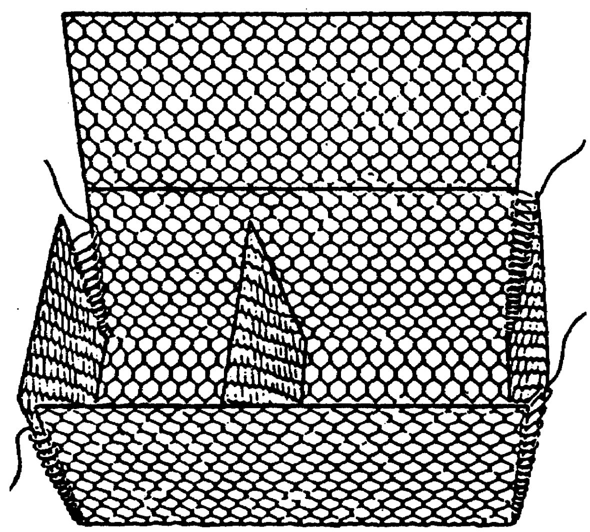


Figure 6-10. Typical gabion.

the following Federal Highway Administration criteria:

- For a 6-inch sieve, 100 percent of the material should pass through.
- For a 3-inch sieve, 75 to 100 percent of the material should pass through.
- For a Number 200 sieve, zero to 25 percent of the material should pass through.
- The PI should be 6 or less.

Excavation Bracing Systems

Bracing systems maybe required to protect the sides of temporary excavations during construction operations. Such temporary excavations may be required for several purposes but are most often needed in connection with the construction of foundations for structures and the placing of utility lines, such as sewer and water pipes.

Shallow Excavations. The term "shallow excavation" refers to excavations made to depths of 12 to 20 feet below the surface, depending principally on the soil involved. The lower limit applies to fairly soft clay soils, while the upper limit generally applies to sands and sandy soils.

Shallow excavations may be made as open cuts with unsupported slopes, particularly when the excavation is being done above the water table, *Chapter 10* gives recommendations previously given relative to safe slopes in cuts that are applicable here if the excavation is to remain open for any length of time. If the excavation is purely temporary in nature, most sandy soils above the water table will stand at somewhat steeper slopes (as much as 1/2 to 1 for brief periods), although some small slides may take place. Clays may be excavated to shallow depths with vertical slopes and will remain stable briefly. Generally, bracing cuts in clay that extend to depths of 5 feet or more below the surface are safer unless flat slopes are used.

Even for relatively shallow excavations, using unsupported cuts may be unsatisfactory for several reasons. Cohesive soils may stand on steep slopes temporarily, but bracing is frequently needed to protect against a sudden cave-in. Required side slopes, particularly in loose, granular soils, may be so flat as to require an excessive amount of excavation. If the excavation is being done close to other structures, space maybe limited, or the consequences of the failure of a side slope may be very serious. Considerable subsidence of the adjacent ground may take place, even though the slope does not actually fail. Finally, if the work is being done below the water table, the excavation may have to be surrounded with a temporary structure that permits the excavation to be unwatered.

Narrow Shallow Excavations. Several different schemes may be used to brace the sides of a narrow shallow excavation. Two of these schemes are shown in *Figure 6-11).*

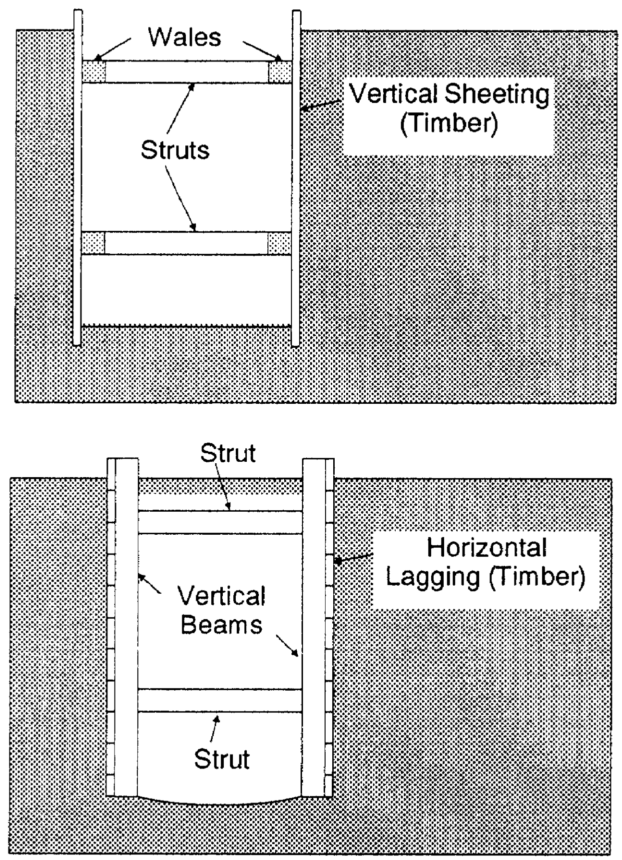


Figure 6-11. Bracing a narrow shallow excavation.

In the first scheme, timber planks are driven around the boundary of the excavation to form what is called vertical sheeting. The bottom of the sheeting is kept at or near the bottom of the pit or trench as excavation proceeds. The sheeting is held in place by means of horizontal beams called wales. These wales are usually supported against each other by means of horizontal members called struts, which extend from one side of the excavation to the other. The struts may be cut slightly long, driven into place, and held by nails or cleats. They may also be held in position by wedges or shims. Hydraulic or screw-type jacks can be used as struts.

The second scheme uses horizontal timber planks to form what is called horizontal lagging. The lagging, in turn, is supported by vertical solid beams and struts. If the excavation is quite wide, struts may have to be braced horizontally or vertically or both.

Bracing systems for shallow excavations are commonly designed on the basis of experience. Systems of this sort represent cases of incomplete deformation, since the bracing system prevents deformation at some points while permitting some deformation at others.

Members used in bracing systems should be strong and stiff. In ordinary work, struts vary from 4-inch to 6-inch timbers for narrow cuts up to 8-inch by 8-inch timbers for excavations 10 or 12 feet wide. Heavier timbers are used if additional safety is desired. Struts are commonly spaced about 8 feet horizontally and from 5 to 6 feet vertically. Lagging or sheeting is customarily made from planks from 6 to 12 inches wide, with the minimum thickness usually being about 2 inches.

Wide Shallow Excavations. If the excavation is too wide to be cross braced by the use of struts, vertical sheeting may be used (see *Figure 6-12).* The wales are supported by inclined braces, which are sometimes called rakes. The rakes, in turn, react against kicker blocks that are embedded in the soil. As the excavation is deepened, additional wales and braces may be added as necessary to hold the sheeting firmly in position. The success of this system depends on the soil in the bottom of the excavation being firm enough to provide adequate support for the blocks.

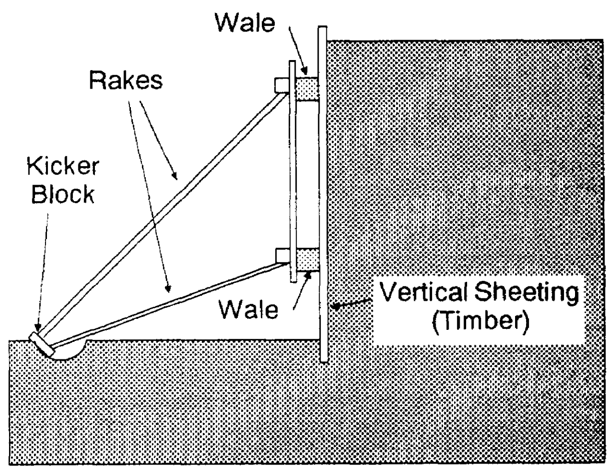


Figure 6-12. Bracing a wide shallow excavation.