Retaining Wall Types & Design Detailing

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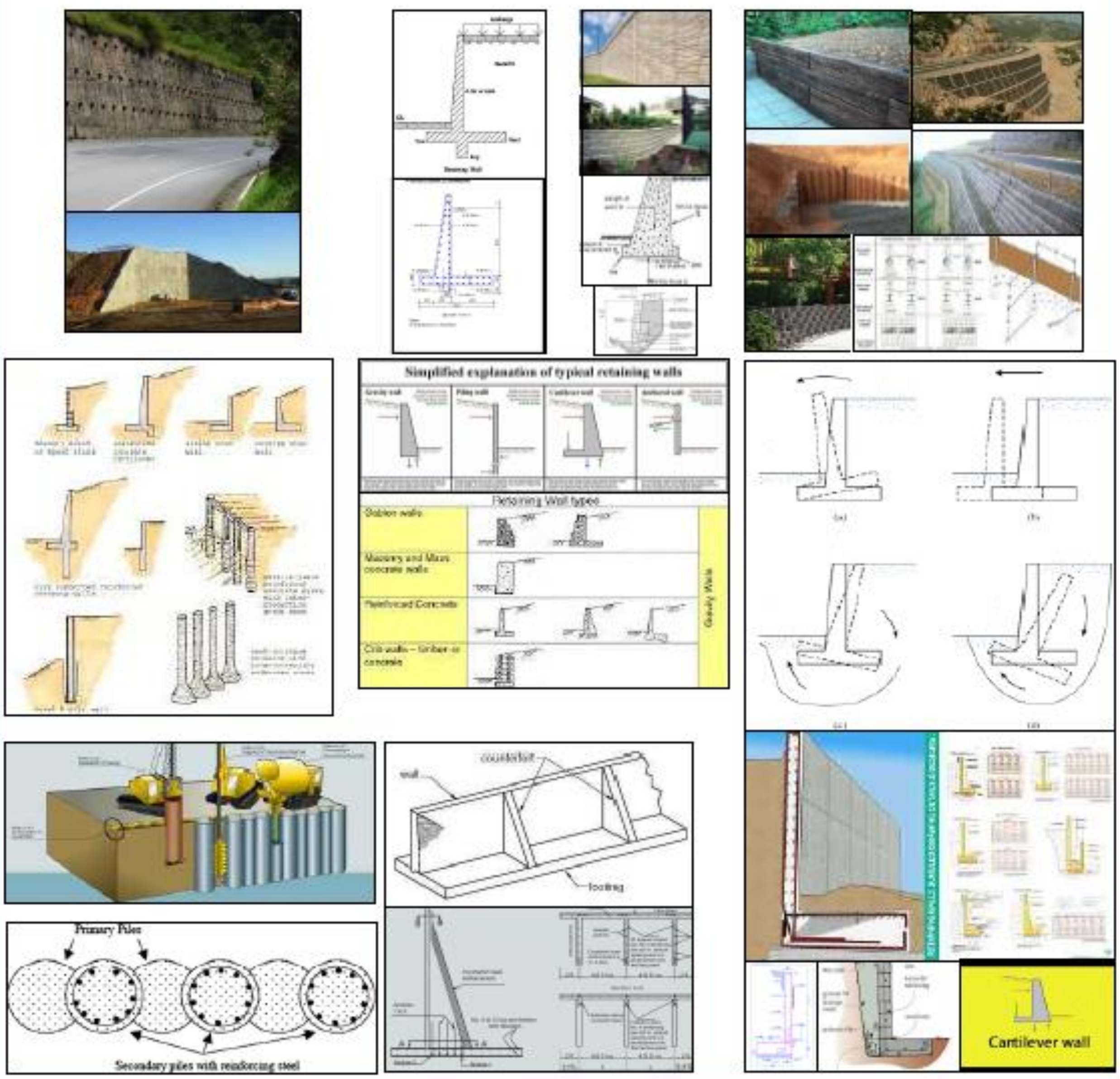
Kurdistan Engineering Union-March 2020



Introduction

A retaining wall is a structure built for the purpose of holding back, or retaining or providing one-sided lateral confinement of soil or other loose material. The loose material being retained pushes against the wall, tending to overturn and slide it.

Retaining walls are used in many design situations where there are abrupt changes in the ground slope. Perhaps the most obvious examples to the reader occur along highway or railroad cuts and fills.

Often retaining walls are used in these locations to reduce the quantities of cut and fill as well as to reduce the right-of-way width required if the soils were allowed to assume their natural slopes. Retaining walls are used in many other locations as well, such as for bridge abutments, basement walls, and culverts.

Several different types of retaining walls are discussed in the next section, but whichever type is used, there will be three forces involved that must be brought into equilibrium:
(1) the gravity loads of the concrete wall and any soil on top of the footing (the so-called *developed weight*)
(2) the lateral pressure from the soil
(3) the bearing resistance of the soil.
In addition, the stresses within the structure have to be within permissible values, and the loads must be supported in a manner such that undue settlements do not occur. A retaining wall must be designed in such a way that the concrete elements that make up the wall comply with the ACI Code using, for the most part, principles already discussed in this text. In addition, the overall stability of the wall must be ensured.
The wall may slide or tip over due to global instability without failure of the concrete elements.
Retaining walls are used to provide lateral resistance for a mass of earth or other material to accommodate a transportation facility.
These walls are used in a variety of applications including right-of-way restrictions, protection of existing structures that must remain in place, grade separations, new highway embankment construction, roadway widening, stabilization of slopes, protection of environmentally sensitive areas, staging, and temporary support including excavation or underwater construction support, etc.

Generally, a retaining wall is any constructed wall that restrains soil or other material at locations having an abrupt change in elevation. They are used to retain soil, rock or other materials in a vertical condition. Hence, they provide a lateral support to vertical slopes of soil that would otherwise collapse into a more natural shape.

Types of Concrete Retaining Walls

Retaining walls are generally classed as being gravity or cantilever types, with several variations possible. These are described in the paragraphs to follow, with reference being made to Figure 13.1.

Gra*vity retaining wall*, shown in Figure 13.1(a), is used for walls of up to about 10 ft to 12 ft in height. It is usually constructed with plain concrete and depends completely on its own weight for stability against sliding and overturning. It is usually so massive that it is unreinforced. Tensile stresses calculated by the working-stress method are usually kept below, Gravity walls may also be constructed with stone or block masonry.

Semi gravity retaining walls, shown in Figure 13.1(b), fall between the gravity and cantilever types (to be discussed in the next paragraph). They depend on their own weights plus the weight of some soil behind the wall to provide stability. Semi gravity walls are used for approximately the same range of heights as the gravity walls and usually have some light reinforcement.

C*antilever retaining wall, one* of its variations is the most common type of retaining wall. Such walls are generally used for heights from about 10 ft to 25 ft. In discussing retaining walls, the vertical wall is referred to as the *stem*. The outside part of the footing that is pressed down into the soil is called the *toe*, while the part that tends to be lifted is called the *heel*.
These parts are indicated for the cantilever retaining wall of Figure 13.1(c). The concrete and its reinforcing are so arranged that part of the material behind the wall is used along with the concrete weight to produce the necessary resisting moment against overturning. This resisting moment is generally referred to as the *righting moment*.

When it is necessary to construct retaining walls of greater heights than approximately 20 ft to 25 ft, the bending moments at the junction of the stem and footing become so large that the designer will, from economic necessity, have to consider other types of walls to handle the moments. This can be done by introducing vertical cross walls on the front or back of the stem. If the cross walls are behind the stem (i.e., inside the soil) and not visible, the retaining walls are called *counterfort walls*. Should the cross walls be visible (i.e., on the toe side), the walls are called *buttress walls*. These walls are illustrated in parts (d) and (e) of Figure 13.1.

The stems for these walls are continuous members supported at intervals by the buttresses or counterforts. Counterforts or buttresses are usually spaced at distances approximately equal to one-half (or a little more) of the retaining wall heights.

The counterfort type is more commonly used because it is normally thought to be more attractive, as the cross walls or counterforts are not visible. Not only are the buttresses visible on the toe side, but their protrusion on the outside or toe side of the wall will use up valuable space. Nevertheless, buttresses are somewhat more efficient than counterforts because they consist of concrete that is put in compression by the overturning moments, whereas counterforts are concrete members used in a tension situation, and they need to be tied to the wall with stirrups. Occasionally, high walls are designed with both buttresses and counterforts.

Figure 13.2 presents a few other retaining wall (Cantilever L-shape) variations. When a retaining wall is placed at a property boundary or next to an existing building, it may be necessary to use a wall without a toe, as shown in part (a) of the figure, or without a heel, as shown in part (b).

Another type of retaining wall very often encountered is the bridge abutment shown in part(c) of the figure.

Abutments may very well have wing wall extensions on the sides to retain the soil in the approach area. The abutment, in addition to other loads, will have to support the end reactions from the bridge.

The use of precast retaining walls is becoming more common each year. The walls are built with some type of precast units, and the footings are probably poured in place. The results are very attractive, and the units are high-quality concrete members made under "plant controlled" conditions. Less site preparation is required, and the erection of the walls is much quicker than cast-in-place ones. The precast units can later be disassembled and the units used again.

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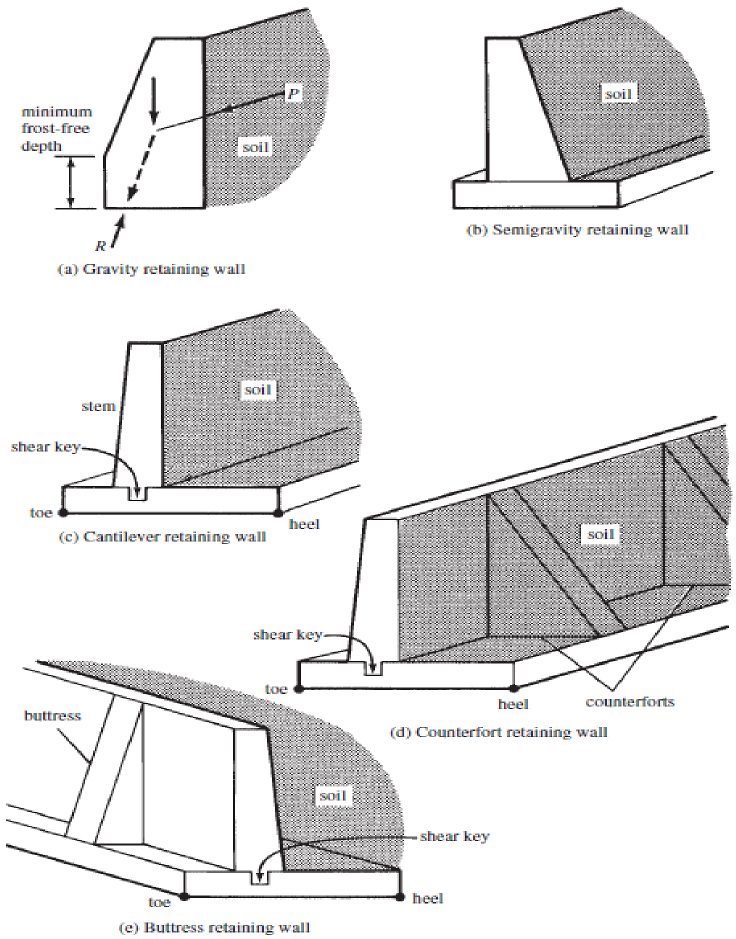


FIGURE 13.1 Retaining wall.

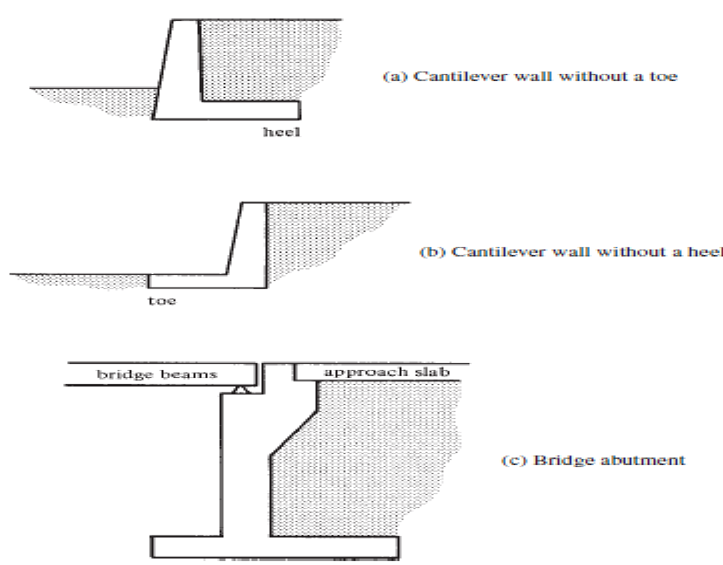


FIGURE 13.2 More retaining walls.

Other types of precast retaining walls

consist of walls or sheeting actually driven into the ground before excavation. Also showing promise are *gabions*, or wire baskets of stone, used in conjunction with geotextile-reinforced embankments.

Modular Gravity Walls

Modular walls are also known as externally stabilized gravity walls as these walls resist external forces by utilizing self-weight. Modular walls have prefabricated modules/components which are considered proprietary. The construction is bottom-up construction mostly used in fill situations.

Modular Block Gravity Walls

Modular block concrete facings are used without soil reinforcement to function as an externally stabilized gravity wall. The modular blocks are prefabricated dry cast or wet cast concrete blocks and the blocks are stacked vertically or slightly battered to resist external forces. The concrete blocks are either solid concrete or hollow core concrete blocks. The hollow core concrete blocks are filled with crushed aggregates or sand. Modular block gravity walls are limited to a maximum design height of 8 feet under optimum site geometry and soils conditions, but site conditions generally dictate the need for MSE walls when design heights are greater than 5.5 feet. Walls with a maximum height of less than 4 feet are deemed as “minor retaining walls”

Prefabricated Bin, Crib and Gabion Walls

-*Bin Walls*

Concrete and metal bin walls are built of adjoining open or closed faced bins and then filled with soil/rocks. Each metal bin is comprised of individual members bolted together. The concrete bin wall is comprised of prefabricated interlocking concrete modules. These wall systems are proprietary wall systems.

-*Crib Walls*

Crib walls are constructed of interlocking prefabricated units of reinforced or unreinforced concrete or timber elements. Each crib is comprised of longitudinal and transverse members. Each unit is filled with free draining material. These wall systems are proprietary wall systems.

-*Gabion Walls*

Gabion walls are constructed of steel wire baskets filled with selected rock fragments and tied together. Gabions walls are flexible, free draining and easy to construct. These wall systems are proprietary wall systems. Maximum heights are normally less than 21 feet. These walls are desirable where equipment access is limited. The wires used for constructing gabions baskets must be designed with adequate corrosion protection.

Mechanically Stabilized Earth (MSE) Walls

Mechanically Stabilized Earth (MSE) walls include a selected soil mass reinforced with metallic or geosynthetic reinforcement. The soil reinforcement is connected to a facing element to prevent the reinforced soil from sloughing. Construction of these walls is staged as bottom-up construction. These can be constructed in cut and fill situations, but are better suited to fill sites. MSE walls are normally used for wall heights between 10 to 40 feet. A brief description of various types of MSE walls is given below:

-*Precast Concrete Panel MSE Walls:*

These types of walls employ a metallic strip or wire grid reinforcement connected to precast concrete panels to reinforce a selected soil mass. The concrete panels are usually 5’x5’ or 5’x10’ size panels. These walls are proprietary wall systems.

-*Modular Block Facing MSE Wall:*

Prefabricated modular concrete block walls consist of almost vertically stacked concrete modular blocks and the soil reinforcement is secured between the blocks at predetermined levels. Metallic strips or geogrids are generally used as soil reinforcement to reinforce the selected soil mass. Concrete blocks are either solid or hollow core blocks, and must meet freeze/thaw requirements. The hollow core blocks are filled with aggregates or sand. These types of walls are proprietary wall systems.

-*Geotextile/Geogrids/Welded Wire Faced MSE Walls:*

These types of MSE walls consist of compacted soil layers reinforced with continuous or semi-continuous geotextile, geogrid or welded wire around the overlying reinforcement. The wall facing is formed by wrapping each layer of reinforcement around the overlying layer of backfill and re-embedding the free end into the backfill. These types of walls are used for temporary or permanent applications. Permanent facings include shotcrete, gunfight, galvanized welded wire mesh, cast-in-place concrete or prefabricated concrete panels.

Soil Nail Walls

Soil nail walls are internally stabilized cut walls that use in-situ reinforcement for resisting earth pressures. The large diameter rebars (generally #10 or greater) are typically used for the reinforcement. The construction of soil nail walls is staged top-down and soil nails are installed after each stage of excavation. Soil nail walls have been installed to heights of 60.0 feet or more but Shotcrete can be applied as a facing. The facing of a soil nail wall is typically covered with vertical drainage strips located over the nail then covered with shotcrete. Soil nail walls are used for temporary or permanent construction.

Rock Walls

Rock walls are also known as 'Rockery Walls'. These types of gravity walls are built by stacking locally available large stones or boulders into a trapezoid shape. These type of Retaining wall which is widely used in our country almost in village to retain soil and make step by step retaining wall especially in mountainy land which have different level of land walls are highly flexible and height of these walls is generally limited to approximately 8.0 feet. A layer of gravel and geotextile is commonly used between the stones and the retained soil.

Rockeries can be generally defined as rough rocks stacked in an "interlocking" pattern without concrete, mortar, or steel reinforcement. Neither mechanical nor physical connections are made between the individual rocks; "interlocking" is accomplished through proper rock layout, rock weight, and frictional interaction. Various terms have been used to describe rockeries, including "rock breast walls," "rockery walls," "dry-stack walls," "stone walls," and "rock walls." The terms used to describe rockeries often reflect the intended use, and, in some cases, preconceptions regarding rockeries.

There is some disagreement within the engineering community as to whether rockeries should be considered earth retaining structures. The City of Seattle, Washington, specifically states rockeries should not be used for earth retention purposes, but can be used as an aesthetic treatment for an otherwise stable slope or to provide erosion protection (slope armor).

The City of Seattle rockery guidelines appear to have been adopted in Washington allow the use of rockeries as retaining structures, although they require engineered design for any rockeries over 0.9 m (3 ft) tall .Some researchers have acknowledged that rockeries can serve as retaining structures and have developed equations especially designed to evaluate the stability of rockeries retaining both native soils and fills. Conceding that while rockeries are best implemented as decorative architectural features or as slope protection for stable slopes, there is an increasing tendency to use rockeries for stabilization of over steepened cut slopes or for retention of fill slopes. Despite the different definitions and attitudes toward rockeries, they have been successfully designed and constructed to heights up to 7.6 m (25 ft) in the Pacific Northwest and northern California over the last decade.

For the purpose of this study, a rockery is defined as an engineered system of stacked angular rocks placed without mortar in an approximate "running bond" pattern. Rock dimensions are generally greater than 450 mm (18 in) and rock weights generally not greater than 90 kg (200 lb.).

Stability of the system is achieved through the mass of the rocks and inter-rock friction.

A rockery can further be defined as either protecting (i.e., it only supports itself and armors the underlying slope) or retaining (i.e., it supports itself and resists lateral earth pressures). The average thickness of protecting rockeries is generally less than retaining rockeries. Rockeries are typically specified by their:

- Height (H).
- Base Width (B).
- Face batter angle, typically between 4V:1H and 6V:1H.
- Individual rock weight and/or size.

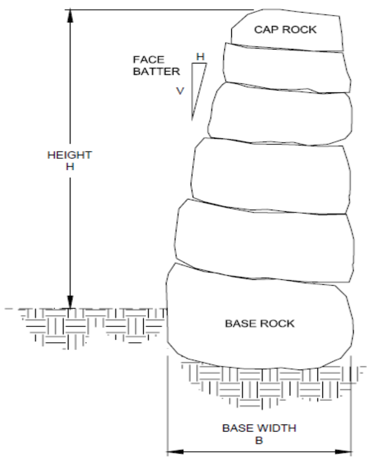


Figure 2. Graphic. Diagram showing definitions of height (H), base width (B), face batter, and relative rock sizes.

A diagram showing the rockery parameters defined above is presented as Figure 2. Small landscaping walls comprised of cobble-sized rounded rocks can be often be found retaining 0.3 to 0.6 m (1 to 2 ft) of soil, often in garden or landscaping applications. These walls are typically not engineered and are often constructed mainly for aesthetic purposes; therefore, they are not considered rockeries for the purposes of this study.

Gray & Satir conclude rockery stability is governed by the rockery face batter angle and H/B ratio, which is consistent with the previous references discussed. They believe H/B should typically, not exceed 3. Furthermore, they indicate that typical base rock widths are about 0.6 m (2 ft), and, therefore, typically rockery heights are about 1.8 m (6 ft). The Gray & Satir text provides a closed form solution that can be used to evaluate rockery stability under the proper conditions. Because, like previous researchers, they concluded stability is typically governed by overturning (in lieu of inter-rock shear and bulging), their equations were developed to solve for overturning stability.

Figures 16 and 17 present the Gray& Satir equations that can be used to compute H/B ratios as a function of the properties of the retained soil, facing rocks, and desired overturning factor of safety. It should be noted that there is a minor error in the equations presented in the textbook that has been corrected in the equations presented throughout this report. The corrected equations have been confirmed as correct by Professor Gray (personal communication).

$$\left(\frac{H}{B}\right) = \frac{0.5b \pm \sqrt{\frac{b^2}{4} + \frac{0.33(FS_{OT})\gamma_S \gamma_R K_A \cos\phi}{\sin\alpha}}}{\frac{0.33(FS_{OT})\gamma_S K_A \cos\phi}{\sin\alpha}}$$

Figure 16. Equation. Height-to-base-width (H/B) as a function of factor of safety, rockery inclination, backslope inclination, and soil and rock properties, from Gray & Satir

$$b = \left[\frac{\gamma_R \cos\alpha}{\sin^2\alpha} + (FS_{OT})K_A \gamma_S \sin\phi\right]$$

Figure 17. Equation. Definition of the term "b" in Figure 16.

The equations presented in Figures 16 and 17 were developed assuming angular rocks; modifications are required for rounded rocks. These equations also neglect backfill cohesion, and, therefore, may be conservative for some circumstances. The equations indirectly address backslope inclination through the use of the active earth pressure coefficient in addition to the equations provided above, Gray & Satir also provide a schematic rockery diagram with several rules of thumb, including:

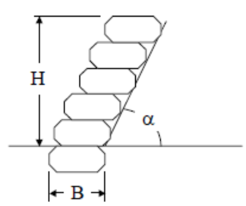


Figure 18. Graphic. Assumed geometric relationships to be used for equations shown in Figures 16 and 17.

· Embedding the base rock, a minimum of 300 mm (12 in) below the ground surface.
· Utilizing a rockery face batter less than 3V:1H.
· Using a cap rock with a minimum width of 400 mm (16 in).
· Designing for a maximum backslope inclination of 1V:2H.
· Placing a layer of free-draining gravel behind the rockery that is tied into a drainage pipe at the base. The gravel layer should be a minimum 200 mm (8 in) wide with a gradation between 50 and 100 mm (2 and 4 in).
· Designing for a maximum height of 3 m (10 ft).

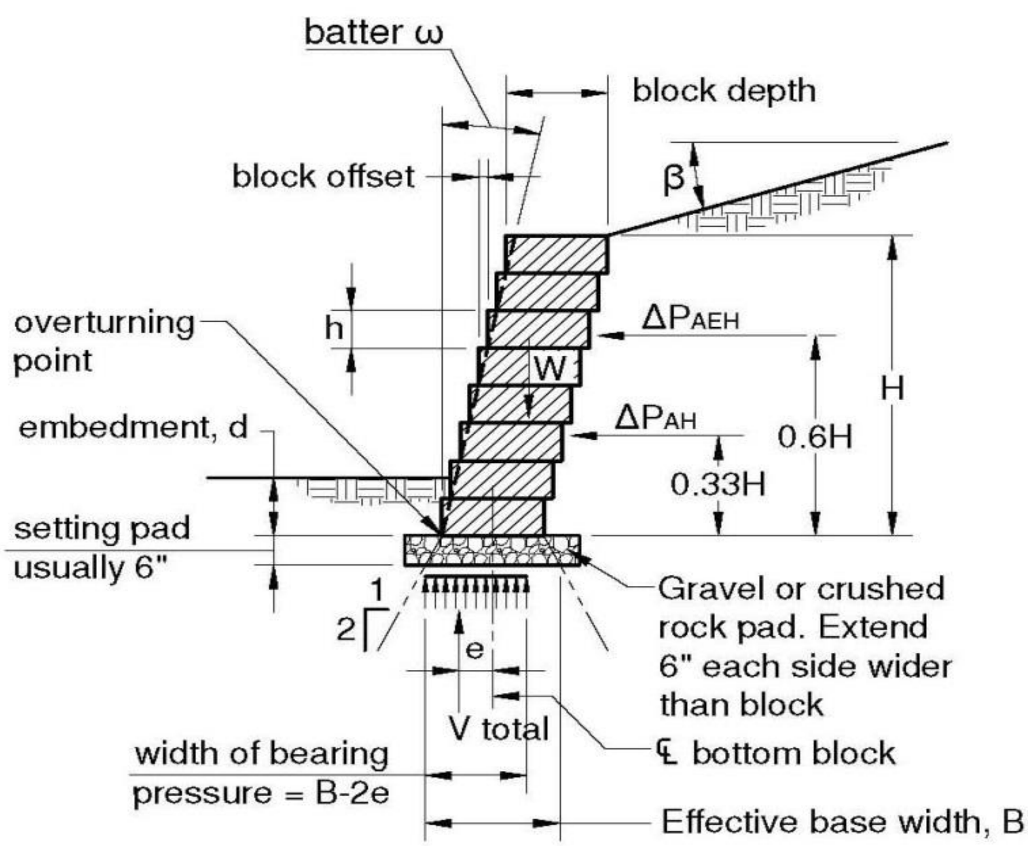
Many of these recommendations are similar to those previously discussed, including the minimum embedment, rockery drainage, and maximum backslope inclination. Of additional interest is that much of the early work for the Gray & Satir textbook was originally published without the equations presented in Figures 16 and 17 in the United States Department of Agriculture, Natural Resources Conservation Service Engineering Field Handbook (Chapter18) in October 1992. Although the Engineering Field Handbook implementation of the rockery design methods proposed by Gray & Satir appear much less rigorous than the later textbook, it appears the Handbook is still in use by some Federal agencies.

Segmental Block Walls

Segmental Blocks are concrete blocks with compressive strength of 3,000 psi or greater, and, in the US, they are manufactured per proprietary designs at licensed local plants. The blocks come in many choices of texture, color, sizes, and configurations. The blocks vary in size, with the most commonly used blocks being 8-inch high with depths varying from 10” to 24”. The block width for the most commonly used blocks is 18 inches. Blocks with dimensions smaller than these are available for non-engineered landscape applications for retaining heights of about three feet or less. All of these blocks weigh between 30 and 110 lbs each. So called “big blocks” are also available from some vendors, weighing two tons or more and placed by small cranes. The blocks are designed to allow construction of walls with vertical batter -- angle of the wall face to the vertical -- to as much as over 15 degrees from vertical. To control batter most segmental blocks have offset lips or other means, such as pins between units, to control the offsets as successive courses of blocks are placed. Angle of wall batter = tan-1 [(offset per block) / (block height)] Most blocks have interior voids which are infilled with granular backfill material. Weight per square foot of wall surface is often assumed to be 130 pcf for both block weight and infill.

Example segmental block wall

Segmental walls are of two types:
- pure gravity walls where stability depends solely upon the resisting moment of the stacked blocks to exceed the overturning moment of the lateral soil pressure. This stability problem limits the height to four or five feet, although some vendors offer larger blocks enabling greater retained heights.
-Higher walls, the more common type of segmental walls use layers of geogrids placed in the backfill for soil reinforcement as the wall is constructed. This results in a mass of reinforced soil (also termed Mechanically Stabilized Earth, MSE) which can be used on masse to improve resistance to overturning and sliding. To be effective, each layer must be properly connected to the block facing by engaging the geogrid within block joints, and extending behind the wall and beyond the failure plane a distance sufficient for anchorage.
The vertical separation between geogrid layers is usually two- to three blocks, but varies with design requirements. The length of the reinforced zone is usually a minimum of 60% to 70% of the wall height.



Forces on gravity segmental walls

[Retaining Wall Types & Design Detailing]

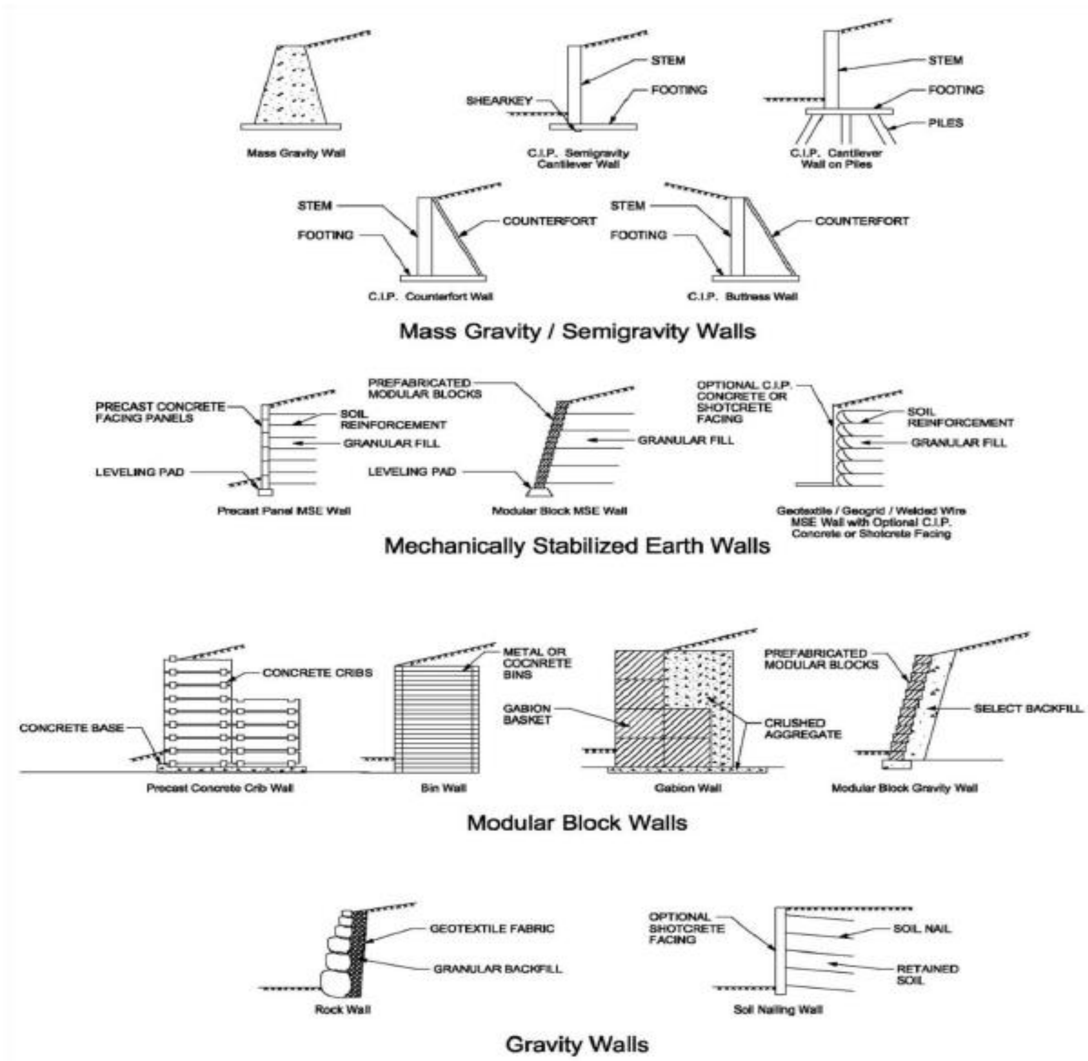


Figure 14.2-1
Gravity Walls

Non-Gravity Walls

Non-gravity walls are classified into cantilever and anchored wall categories. These walls are considered as externally stabilized walls and generally used in cut situations. The walls include sheet pile, soldier pile, tangent and secant pile type with or without anchors. Figure 14.2-2 shows common types of non-gravity walls.

Cantilever Walls

These types of walls derive lateral resistance through embedment of vertical elements into natural ground and the flexure resistance of the structural members. They are used where excavation support is needed in shallow cut situations.

-Cantilever Sheet Pile Walls:

Cantilever sheet pile walls consist of interlocking steel panels, driven into the ground to form a continuous sheet pile wall. The sheet piles resist the lateral earth pressure utilizing the passive resistance in front of the wall and the flexural resistance of the sheet pile. Most sheet pile walls are less than 15 feet in height.

-Soldier Pile Walls:

A soldier pile wall derives lateral resistance and moment capacity through embedment of vertical members (soldier piles) into natural ground usually in cut situations. The vertical elements (usually H piles) may be drilled or driven steel or concrete members. The soil behind the wall is retained by lagging. The lagging may be steel, wood, or concrete. For permanent walls, wall facings are usually constructed of either cast-in-place concrete or precast concrete panels (prestressed, if needed) that extend between vertical elements. Solider pile walls that use precast panels and H piles are also known as post-and-panel walls. Soldier pile walls can also be constructed from the bottom-up. These walls should be considered when minimizing disturbance to the site is critical, such as environmental and/or construction procedures. Soldier pile walls are also suitable for sites where rock is encountered near the surface, since holes for the piles can be drilled/preboard into the rock.

-Tangent and Secant Pile Walls:

A tangent pile wall consists of a single row of drilled shafts (bored piles) installed in the ground. Each pile touches the adjacent pile tangentially. The concrete piles are reinforced using a single steel beam or a steel reinforcement cage. A secant wall, similar to a tangent pile wall, consists of overlapping adjacent piles. All piles generally contain reinforcement, although alternating reinforced piles may be necessary. Secant and tangent wall systems are used to hold earth and water where water tightness is important, and lowering of the water table is not desirable. To improve wall water tightness, additional details can used to minimize water seepage.

Anchored Walls

Anchored walls are externally stabilized non-gravity cut walls. Anchored walls are essentially the same as cantilever walls except that these walls utilize anchors (tiebacks) to extend the wall heights beyond the design limit of the cantilever walls. These walls require less toe embedment than cantilever walls.

These walls derive lateral resistance by embedment of vertical wall elements into firm ground and by anchorages. Most commonly used anchored walls are anchored sheet pile walls and soldier pile walls. Tangent and secant walls can also be anchored with tie backs and used as anchored walls. The anchors can be attached to the walls by tie rods, bars or wire tendons. The anchoring device is generally a Deadman, screw-type, or grouted tieback anchor. Anchored walls can be built to significant heights using multiple rows of anchors.

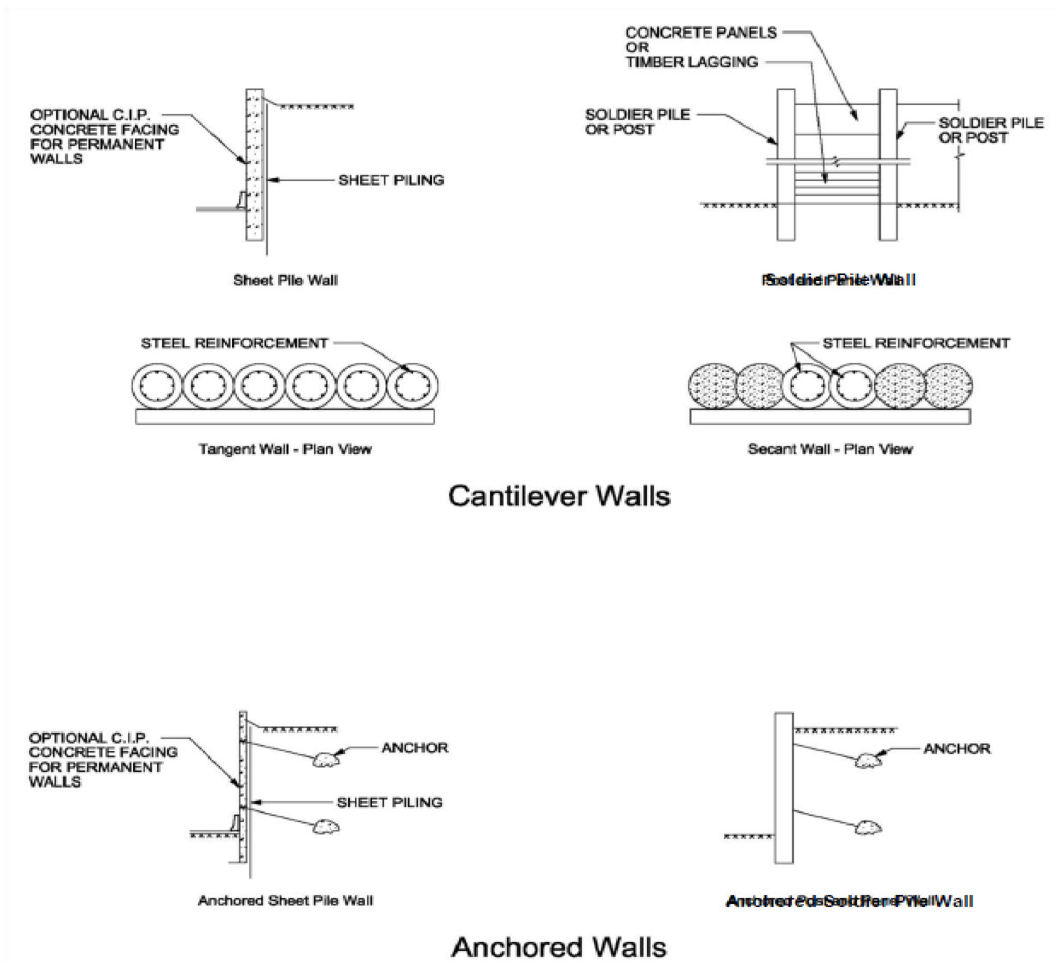


Figure 14.2-2
Non-Gravity Walls

Tiered and Hybrid Wall Systems

A tiered wall system is a series of two or more walls, with each wall set back from the underlying walls. The upper wall exerts an additional surcharge on the lower lying wall and requires special design attention. The design of these walls has not been discussed in this chapter. Hybrids wall systems combine wall components from two or more different wall systems and provide an alternative to a single type of wall used in cut or fill locations. These types of walls require special design attention as components of these walls require different magnitudes of deformation to develop loading resistance. The design of such walls will be on a case-by-case basis, and is not discussed in this chapter.

Some examples of tiered and hybrid walls systems are shown in Figure 14.2-3.

Temporary Shoring

Temporary shoring is used to protect existing transportation facilities, utilities, buildings, or other critical features when safe slopes cannot be made for structural excavations. Shoring may be required within the limits of structures or on the approach roadway due to grade changes or staged construction. Shoring should not be required nor paid for when used primarily for the convenience of the contractor. Temporary shoring is designed by the contractor and may consist of a wall system, or some other type of support. MSE walls with flexible facings and sheet pile walls are commonly used for temporary shoring.

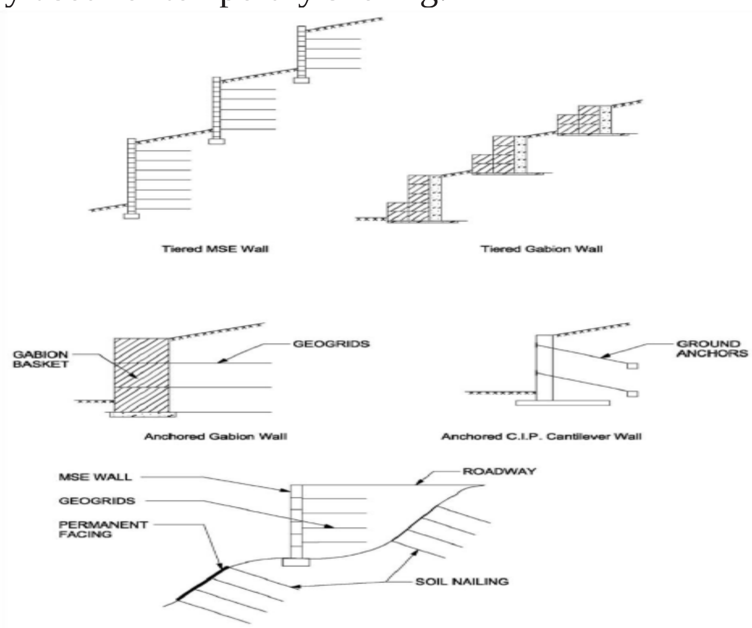


Figure 14.2-3
Tiered & Hybrid Wall Systems

Wall Selection Criteria

Generally, the objective of selecting a wall system is to determine an appropriate wall system that is practical to construct, structurally sound, economic, aesthetically pleasing, environmentally consistent with the surroundings, and has minimal maintenance problems.
With the development of many new wall systems, designers have the choice of selecting many feasible wall systems that can be constructed on a given highway project. Designers are encouraged to evaluate several feasible wall systems for a particular project where wall systems can be economically constructed. After consideration of various wall types, a single type should be selected for final analyses and design. Wall designers must consider the general design concepts. In general, selection of a wall system should include, but not limited to the key factors described in this section for consideration when generating a list of acceptable retaining wall systems for a given site. The designer must determine if the wall system is permanent or temporary.

-Cut Walls, are generally constructed from the top down and used for both temporary and permanent applications. Cantilever sheet pile walls are suitable for shallower cuts. If a deeper cut is required to be retained, a key question is to determine the availability of right-of-way. Subsurface conditions such as shallow bedrock also enter into considerations of cut walls. Anchored walls, soil nail walls, and anchored soldier pile walls may be suitable for deeper cuts although these walls require either a larger permanent easement or permanent right-of-way.

-Fill Walls, constructed in fill locations are typically used for permanent construction and may require large right-of-way to meet the base width requirements. The necessary fill material may be required to be granular in nature. These walls use bottom up construction and have typical cost-effective ranges. Surface conditions must also be considered. For instance, if soft compressible soils are present, walls that can tolerate larger settlements and movements must be considered. MSE walls are generally more economical for fill locations than CIP cantilever walls.

-Cut/Fill Wall, CIP cantilever and prefabricated modular walls are most suitable in cut/fill situations as the walls are built from bottom up, have narrower base widths and these walls do not rely on soil reinforcement techniques to provide stability. These types of walls are suitable for both cut or fill situations.

Drainage

One of the most important items in designing and constructing successful retaining walls is the prevention of water accumulation behind the walls. If water is allowed to build up there, the result can be great lateral water pressure against the wall and perhaps an even worse situation in cold climates due to frost action.

The best possible backfill for a retaining wall is a well-drained and cohesionless soil. This is the condition for which the designer normally plans and designs. In addition to agranular backfill material, weep holes of 4 in. or more in diameter (the large sizes are used for easy cleaning) are placed in the walls approximately 5 ft to 10 ft on center, horizontally and vertically, as shown in Figure 13.3(a). If the backfill consists of a coarse sand, it is desirable to put a few shovels of pea gravel around the weep holes to try to prevent the sand from stopping up the holes.

Weep holes have the disadvantages that the water draining through the wall is somewhat unsightly and also may cause a softening of the soil in the area of the highest soil pressure (under the footing toe). A better method includes the use of a 6-in. or 8-in. perforated pipe in a bed of gravel running along the base of the wall, as shown in Figure 13.3(b). Unfortunately, both weep holes and drainage pipes can become clogged, with the result that increased water pressure can occur.

Manufactured drainage blankets or porous mats placed between the wall and the soil allow moisture to migrate freely to drainage systems, such as in Figure 13.3(b). The drainage methods described in the preceding paragraphs are also quite effective for reducing frost action in colder areas. Frost action can cause very large movements of walls, not just in terms of inches but perhaps even in terms of a foot or two, and over a period of time can lead to failures. Frost action, however, can be greatly reduced if coarse, properly drained materials are placed behind the walls.

The thickness of the fill material perpendicular to a wall should equal at least the depth of frost penetration in the ground in that area. The best situation of all would be to keep the water out of the backfill altogether. Such a goal is normally impossible, but sometimes the surface of the backfill can be paved with asphalt or some other material, or perhaps a surface drain can be provided to remove the water or it may be possible in some other manner to divert the water before it can get to the backfill.

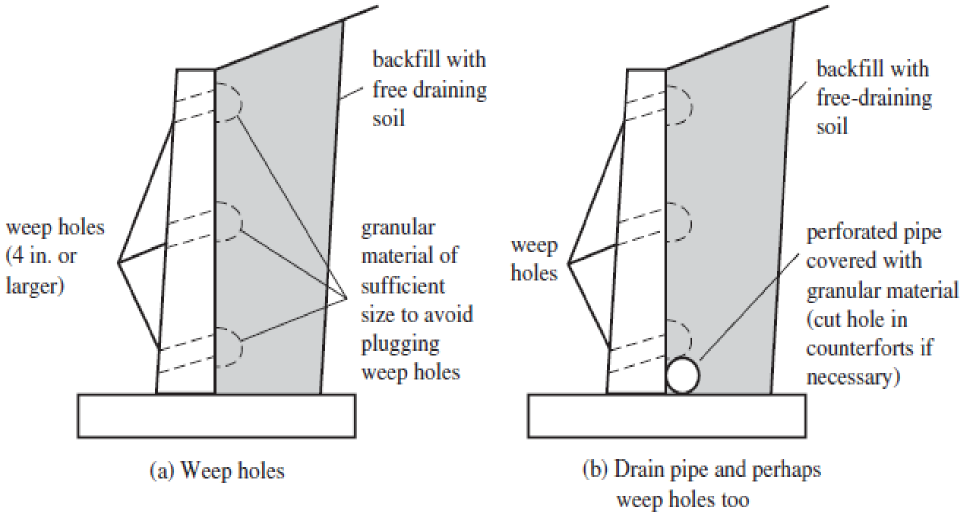


FIGURE 13.3 Retaining wall drainage

Estimating the Sizes of Cantilever Retaining Walls

The statically analysis of retaining walls and consideration of their stability as to overturning and sliding are based on service-load conditions. In other words, the length of the footing and the position of the stem on the footing are based entirely on the actual soil backfill, estimated lateral pressure, coefficient of sliding friction of the soil, and so on. On the other hand, the detailed designs of the stem and footing and their reinforcing are determined by the strength design method. To carry out these calculations, it is necessary to multiply the service loads and pressures by the appropriate load factors. From these factored loads, the bearing pressures, moments, and shears are determined for use in the design.
Thus, the initial part of the design consists of an approximate sizing of the retaining wall. Although this is actually a trial-and-error procedure, the values obtained are not too sensitive to slightly incorrect values, and usually one or two trials are sufficient. Various rules of thumb are available with which excellent initial size estimates can be made. In addition, various handbooks present the final sizes of retaining walls that have been designed for certain specific cases. This information will enable the designer to estimate very well the proportions of a wall to be designed. The CRSI Design Handbook is one such useful reference.3 In the next few paragraphs, suggested methods are presented for estimating sizes without the use of a handbook. These approximate methods are very satisfactory as long as the conditions are not too much out of the ordinary.

Height of Wall

The necessary elevation at the top of the wall is normally obvious from the conditions of the problem. The elevation at the base of the footing should be selected so that it is below frost penetration in the particular area—about 3 ft to 6 ft below ground level in the northern part of the United States. From these elevations, the overall height of the wall can be determined.

Stem Thickness

Stems are theoretically thickest at their bases because the shears and moments are greatest there. They will ordinarily have total thicknesses somewhere in the range of 7% to 12% of the overall heights of the retaining walls. The shears and moments in the stem decrease from the bottom to the top; as a result, thicknesses and reinforcement can be reduced proportionately.

Stems are normally tapered, as shown in Figure 13.12. The minimum thickness at the top of the stem is 8 in., with 12 in. preferable. As will be shown in Section 13.10, it is necessary to have a mat of reinforcing in the inside face of the stem and another mat in the outside face. to provide room for these two mats of reinforcing, for cover and spacing between the mats, a minimum total thickness of at least 8 in. is required. The use of the minimum thickness possible for walls that are primarily reinforced in one direction (here it's the vertical bars) doesn't necessarily provide the best economy. The reason is that the reinforcing steel is a major part of the total cost. Making the walls as thin as possible will save some concrete but will substantially increase the amount of reinforcing needed. For fairly high and heavily loaded walls, greater thicknesses of concrete may be economical. If ρ in the stem is limited to a maximum value of approximately (0.18f _
c /fy), the stem thickness required for moment will probably provide sufficient shear resistance without using stirrups. Furthermore, it will probably be sufficiently thick to limit lateral deflections to reasonable values.

For heights up to about 12 ft, the stems of cantilever retaining walls are normally made of constant thickness because the extra cost of setting the tapered formwork is usually not offset by the savings in concrete. Above 12-ft heights, concrete savings are usually sufficiently large to make tapering economical.

Actually, the sloping face of the wall can be either the front or the back, but if the outside face is tapered, it will tend to counteract somewhat the deflection and tilting of the wall because of lateral pressures. A taper or batter of 14 in. per foot of height is often recommended to offset deflection or the forward tilting of the wall.

Base Thickness

The final thickness of the base will be determined on the basis of shears and moments. For estimating, however, its total thickness will probably fall somewhere between 7% and 10% of the overall wall height. Minimum thicknesses of at least 10 in. to 12 in. are used.

Base Length

For preliminary estimates, the base length can be taken to be about 40% to 60% of the overall wall height. A little better estimate, however, can be made by using the method described by the late Professor Ferguson in his reinforced concrete text.4 For this discussion, reference is made to Figure 13.13. In this figure, W is assumed to equal the weight of all the material within area a,b,c&d. This area contains both concrete and soil, but the authors assume here that it is all soil. This means that a slightly larger safety factor will be developed against overturning than assumed. When surcharge is present, it will be included as an additional depth of soil, as shown in the figure.

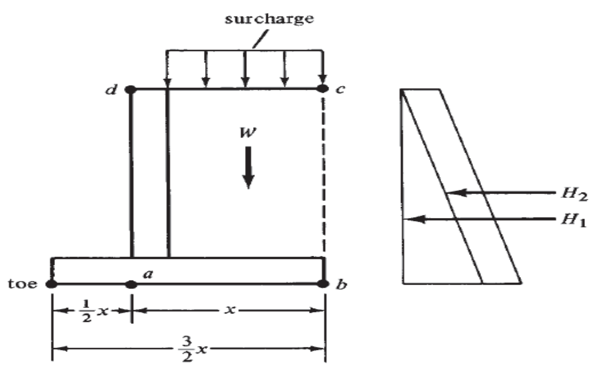


FIGURE 13.13 Forces acting on cantilever retaining wall.

13.9 Estimating the Sizes of Cantilever Retaining Walls

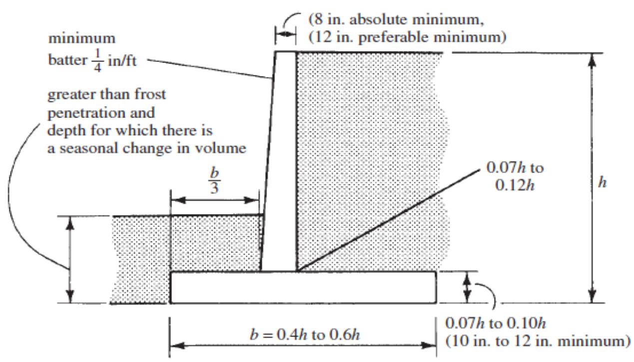


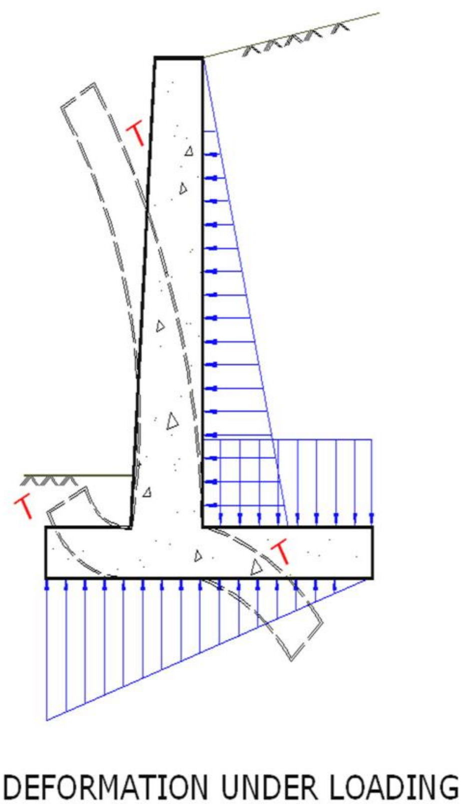
FIGURE 13.14 Rules of thumb for proportioning cantilever retaining walls.

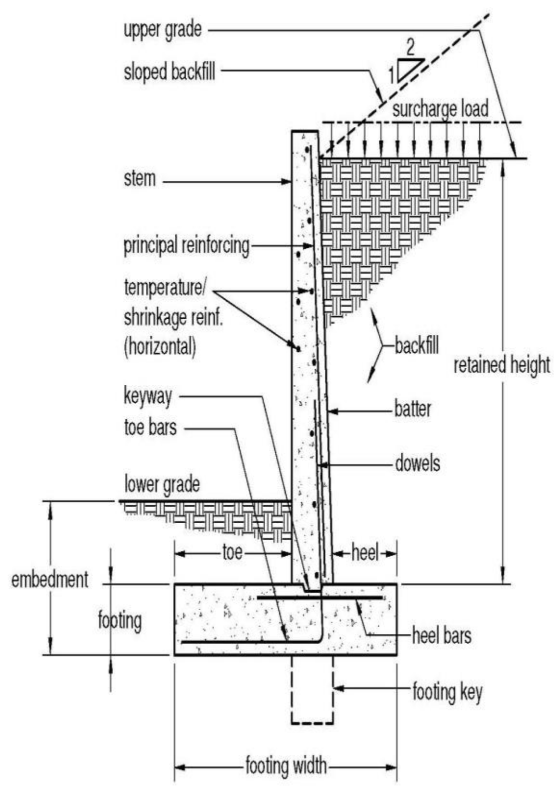
Types of Retaining walls with its' Properties

Wall Type	Effective Height (ft)	Water Tightness	Advantages
CIP Concrete Gravity	3 - 10	Good	• Durable • Meets aesthetic requirement • Requires small quantity of select backfill
CIP Concrete Cantilever	6 - 28	Good	• Durable • Meets aesthetic requirement • Requires small quantity of select backfill
Reinforced CIP Counterfort	26 - 40	Good	• Durable • Meets aesthetic requirement • Requires small quantity of select backfill
Modular Block Gravity	3 - 8	Fair	• Does not require skilled labor or specialized equipment
Metal Bin	6 - 20	Poor	• Does not require skilled labor or specialized equipment
Concrete Crib	6 - 20	Poor	• Does not require skilled labor or specialized equipment
Gabion	6 - 20	Poor	• Does not require skilled labor or specialized equipment
MSE Wall (precast concrete panel with steel reinforcement)	10 – 30	Fair	• Does not require skilled labor or specialized equipment
MSE Wall (modular block and geo-synthetic reinforcement)	6 – 22	Fair	• Does not require skilled labor or specialized equipment
MSE Wall (geotextile/geogrid/ welded wire facing)	6 – 35	Fair	• Does not require skilled labor or specialized equipment
Sheet Pile	6 - 15	Fair	• Rapid construction • Readily available
Soldier Pile	6 - 28	Poor	• Easy construction • Readily available
Tangent Pile	20 - 60	Fair/Poor	• Adaptable to irregular layout • Can control wall stiffness
Secant Pile	14 - 60	Fair	• Adaptable to irregular layout • Can control wall stiffness
Anchored	15 - 35	Fair/Poor	• Rapid construction
Soil Nail	6 - 20	Fair	• Option for top down
Rockery Wall	3 - 10	Poor	• Easy construction • Rapid construction
Segmental walls	3 - 10	Poor	• Easy construction • Rapid construction

Behaviors or structural action of Cantilever Retaining Wall

Behaviors or structural action and design of (stem, heel and toe slabs) are same as that of any cantilever slab, means which sides of concrete element affected by Tension stress Main Reinforcement should applied to resist stress and stay Retaining wall Safe to carry applied vertical, horizontal and soil pressure load .





Main Reinforcement Detailing Location

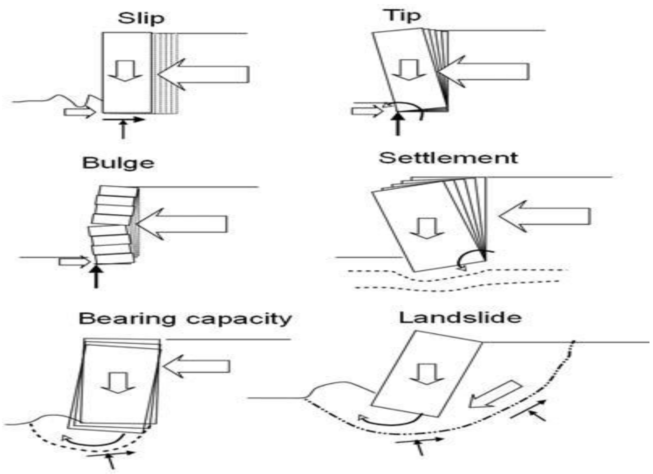
Quality Control During Construction

The internal friction of soil depends in part on the degree of compaction, so the compacted soil density and moisture content are part of the specification, particularly for a high wall. The usual procedure is to specify a required density and moisture content, which are measured with nuclear gauges. A more recent trend is to directly measure the soil internal friction with a rapid in-situ testing method, such as the Borehole Shear Test, as a quality control measure.

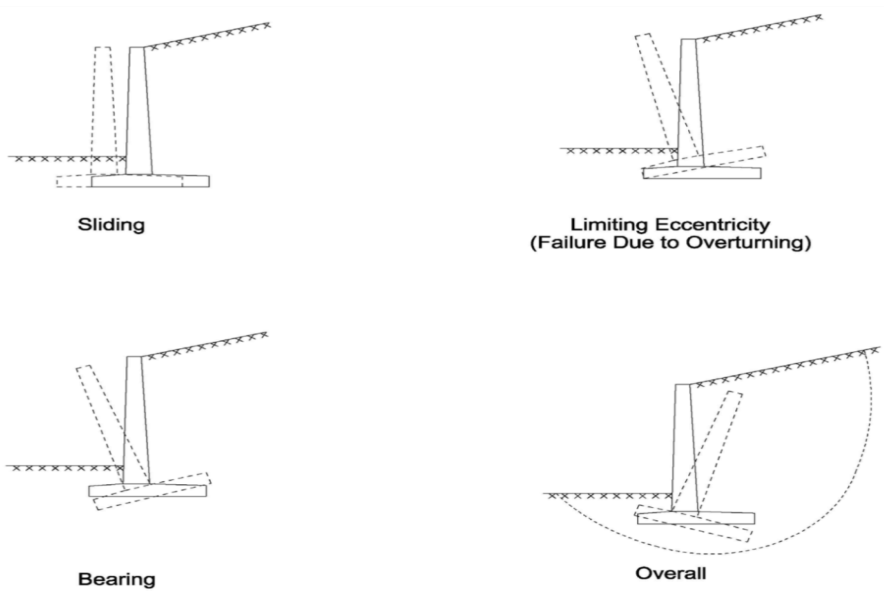
This can eliminate the requirement of empirically correlating strength with density, and is particularly advantageous if the fill soils are variable.

Failure Modes of Retaining Walls

Retaining walls must be designed to resist several different failure modes that include:
- overturning;
- sliding along the base;
-bulging in the center area that may be preliminary to rupture;
-sinking and tilting as a result of eccentric loading and consolidation of the foundation soil;
-sinking caused by a foundation bearing capacity failure; and
-being part of a landslide, referred to as ‘‘global stability.’’
Some of these possibilities are illustrated in Fig. below

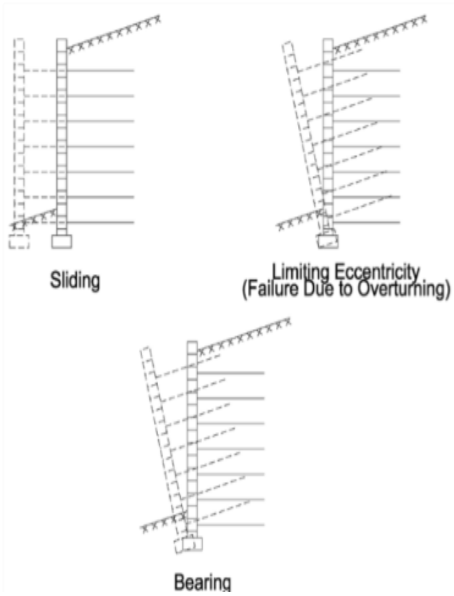


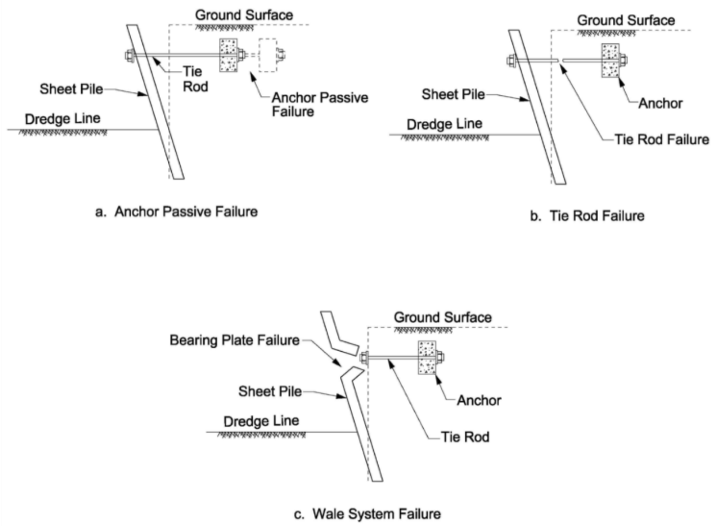
Failure modes for retaining walls



External Stability Failure of CIP Semi-Gravity Walls

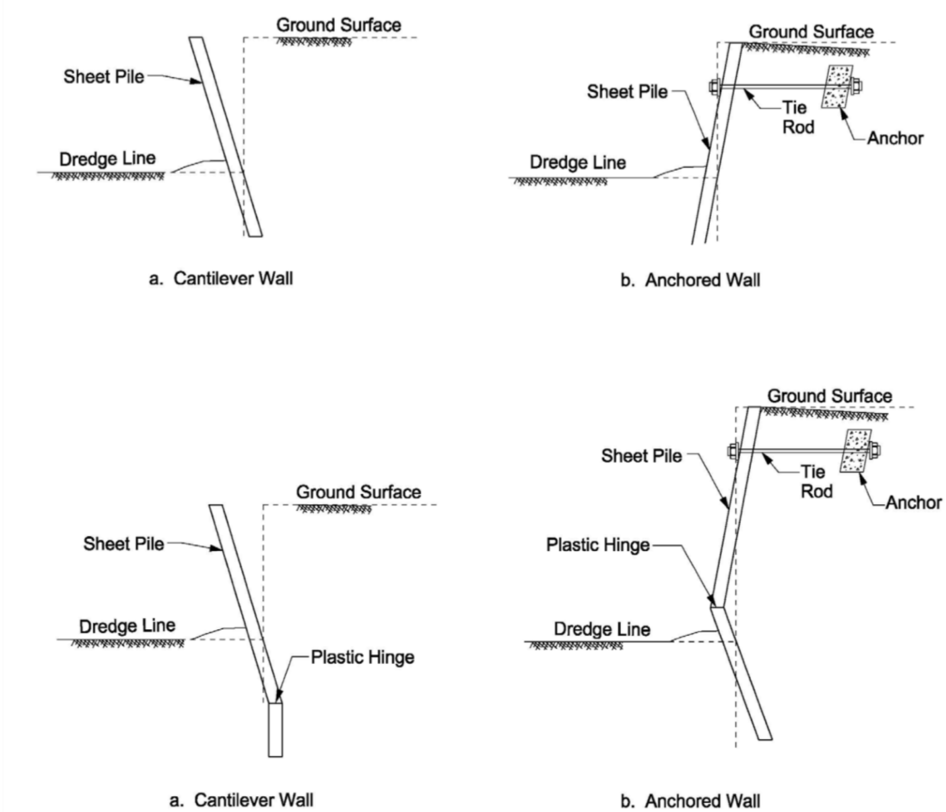
[Retaining Wall Types & Design Detailing]





External Stability Failure of MSE Walls

Flexural Failure of Non-Gravity Walls



Flexural Failure of Non-Gravity Walls

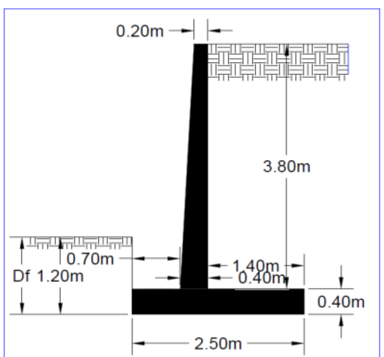
Design of Reinforced Concrete Cantilever retaining wall:

Design a cantilever retaining wall (T type) to retain earth for a height of 3m. The backfill is horizontal. The density of soil is(17kN/m3), Safe Bearing capacity of soil is (180kN/m2). Take the co-efficient of friction between concrete and soil as 0.6. The angle of repose is 30°. Use (fc'=25Mpa) concrete and (fy=420Mpa) steel.

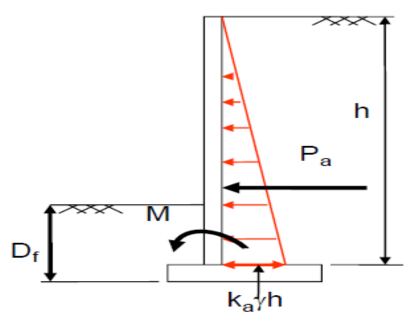
Solution:
Available Data: h' = 3m, SBC= 180kN/m2, γ = 17kN/m3, μ=0.6, φ=30°

**Depth of foundation*

- To fix the height of retaining wall [H]
- H= h' +Df
-Depth of foundation
-Df =$\left(\frac{SBC}{\gamma}\right)\left(\frac{1-sin\emptyset}{1+sin\emptyset}\right)2 \geq 1m$
= 1.16m say 1.2m, Therefore H= 4.2m



Preliminary Dimensions of Retaining Wall



**Proportioning of wall*

- Thickness of base slab=(1/10 to1/14)H
 0.42m to 0. 3m, say 0.40 mm
- Width of base slab=B = (0.5 to 0.6) H
 2.10m to 2.50m say 2.5m
-Toe projection= (1/3 to 1/4)B
0.83m to 0.63m say 0.70m
- Thickness for the stem at the base=(1/14to 1/8)H
0.3m to 0.52m say 0.40m and 0.20m at the top

*Design of stem

Max.soil pressure @base wall=ka* γ *h   (ka=$\frac{1-sin\emptyset}{1+sin\emptyset}=\frac{1-sin30}{1+sin30}$=0.333)

-Ph= ½*ka* γ *(h)^2

=½ x 0.333 * 17 *(3.8)^2=40.90kN

- M = Ph* h/3 = 40.90*3.8/3

=51.80kN-m

Mu= 1.5 * M = 77.7KN-m

-Taking 1m length of wall,

(Here d=400- eff. Cover-$\emptyset/2$=450-50-16/2=342 mm)

- To find steel

- A.st=Mu/{$\emptyset * fy * \left(d-\frac{a}{2}\right)$} say$\left(d-\frac{a}{2}\right)=0.9d$

=77.7*1,000,000/{0.9*420*0.9*342} = 668 mm2

Use Ø16mm(A=200mm2) no. of bar 4 use 5 bars

-use Ø16 @ 200mm c/c

- A.st provided= 1000 mm2 [0.29%]

-A.st min=0.002b*d

=0.002*1000*342=684mm2

A.st max=0.75ρ_b

A.st max=0.75(0.85 β1*(fc'/fy)*(600/600+fy))

=0.75(0.85*0.85*(25/420)*(600/1020))=0.0189

Thus A.st min<A.st Provided<A.st max OK.

A.st secondary and shrinkage use Ø12mm@17cmc/c

-Check for shear strength:

Max shear force @junction between stem &base is

ph= Ph= ½*ka* γ *(h)^2

=40.90kN

Ultimate shear force =1.5*40.9

=61.30 kN

Concrete shear strength=Vc=2Ø*$\sqrt{fc'}$*b*d

=2*0.75*$\sqrt{25}$*1000*342

=2,565 kN>Vu applied ok Thickness of stem safe.

-Now check for Max.solil pressure &Min.soil pressure

q min.=(Total vertical load/Base width)*(1-(6*e/B))

q max.=(Total vertical load/Base width)*(1+(6*e/B))

If q max.<Allowable bearing capacity of soil its ok

Load	Magnitude (kN)	Distance from point a.(m)	Bending moment about point a.(kN.m)
Stem w1	(0.2*3.8/2)*25=9.5	0.7+1/3*0.2=0.76	7.20
Stem w2	0.2*3.58*25=19	0.7+0.3=1.0	19.0
Base slab	2.5*0.4*25=25	2.5/2=1.25	31.25
Back fill	1.4*3.8*17=90.4	1.1+1.4/2=1.8	162.70
summations	143.90		220.15

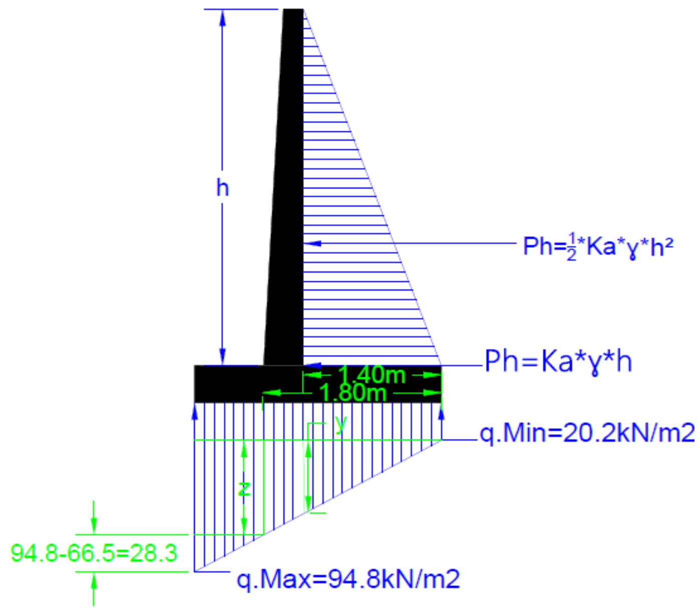
Earth pressure= PH= $\frac{1}{2}*ka*\gamma*(H)^2$
$= \frac{1}{2}*1/3*17*(4.2)^2$
=49.90KN
Overturning Moment=M.O=PH*H/3
=49.9*4.2/3
=69.9KN.m

-Check for Stability
F.O.S=Total Resisting Moment/Total Overturning Moment
=220.10/69.9
=3.14>1.5 ok. The retaining wall safe against overturning.

-Check for Sliding
F.O.S=Total vertical load/Total horizontal load
=143.9/40.9=3.5 >1.5 ok safe against Sliding

-Check for Bearing Capacity (Subsidence)
X=Sum Moment/Sum Vertical Load
= 220.1/143.9
=1.52> B/3=0.83
e=(B/2)-x
=(2.5/2)-1.52
=0.27<B/6 (Kern Area) 2.5/6=0.42 ok the wall safe against bearing capacity

-Now finding Min Soil pressure &Max SOIL pressure
q min.=(Total vertical load/Base width)*(1-(6*e/B))
=(143.9/2.5)(1-(6*0.27/2.5))=20.2Kn/m2
q max.=(Total vertical load/Base width)*(1+(6*e/B))
=(143.9/2.5)(1+(6*0.27/2.5))=94.8Kn/m2
Thus q max.<Allowable bearing capacity of soil its ok



Soil pressure on Retaining Wall

*Design of Heel Slab:

By similarity between two tringles:

Pressure @face stem (y)

y/1.4=(94.8-20.2)/2.5   ; y=41.7Kn/m2

max Moment @ face stem

M due Soil Load +M due Concrete Heel-M due Soil pressure(rectangle & tringle)

Max M=(3.8*1.4*17*1.4/2)+(1.4*0.4*25*1.4/2)-(20.2*1.4*1.4/2)-(1.4*41.7/2*1.4/3)

=63.3+9.8-17.9-13.6=39.8kn-m

A.st=Mu/{$\emptyset * fy * \left(d - \frac{a}{2}\right)$} say$\left(d - \frac{a}{2}\right) = 0.9d$

=39.8*1,000,000/{0.9*420*0.9*342} = 341 mm2<As min

-A.st min=0.002b*d

=0.002*1000*342=684mm2>Ast actual

Use Ø16mm(A=200mm2) no. of bar 4 use 5 bars

-use Ø16 @ 200mm c/c

- A.st provided= 1000 mm2 [0.29%]

-A.st min=0.002b*d

=0.002*1000*342=684mm2

A.st secondary and shrinkage use Ø12mm@17cmc/c

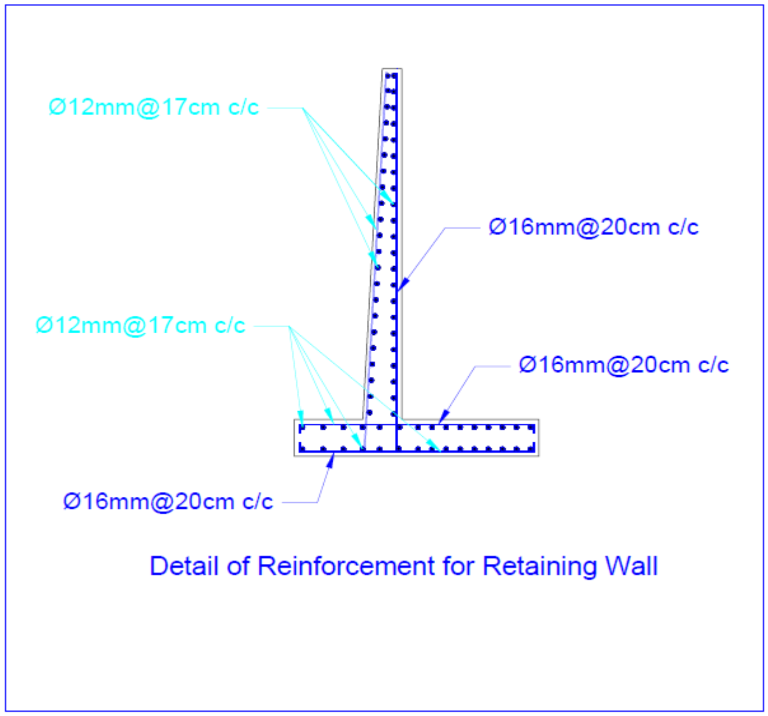
*Design of Toe Slab:

By similarity between two tringles:
Pressure @face stem (z)
z/1.8=(94.8-20.2)/2.5 ; z=66.5Kn/m2
max Moment @ face stem
M due Soil Load +M due Concrete Heel-M due Soil pressure(rectangle & tringle)
Max M=(0.8*0.7*17*0.7/2)+(0.7*0.4*25*0.7/2)-((66.5+20.2)*0.7*0.7/2)-((28.3*0.7/2)*2/3*0.7)
=3.3+2.45- 21.24 - 4.6=20.1kn-m
A.st=Mu/{$\emptyset * fy * \left(d - \frac{a}{2}\right)$} say$\left(d - \frac{a}{2}\right) = 0.9d$
=20.1*1,000,000/{0.9*420*0.9*342} = 172 mm2<As min

-A.st min=0.002b*d
=0.002*1000*342=684mm2>Ast actual
Use Ø16mm(A=200mm2) no. of bar 4 use 5 bars
-use Ø16 @ 200mm c/c
- A.st provided= 1000 mm2 [0.29%]
-A.st min=0.002b*d
=0.002*1000*342=684mm2
A.st secondary and shrinkage use Ø12mm@17cmc/c

-Check for shear
Max shear strength@ Heel =Total vertical load-Soil pressure
=1.4*0.4*25+3.8*1.4*17-20.2*1.4-(41.7*1.4)/2
=14+90.4-28.2-29.2
=47.0kn
Vu=1.5*47
=70.5kn
Concrete shear strength= Vc=2Ø*$\sqrt{fc'}$*b*d
=2*0.75*$\sqrt{25}$*1000*342
=2,565 kN>Vu applied ok Thickness of stem safe.

Retaining Wall Types & Design Detailing



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Reported by ACI Committee 318
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Richard L. Handy , M. G. Spanger

The End