Figures

Photos

Chapter 13. Retaining Structures

Retaining structures are used to support and stabilize the trail bed, cut bank, or fillslope, or to elevate other trail structures. They may be used upslope, within, or downslope of the trail bed, or as part of another structure, such as a bridge abutment, ramp, or cribbed steps.

13.1. Applications

The determination of when a retaining structure is needed and the type of structure that should be constructed requires a careful examination of the existing conditions and the problem to be solved. The following conditions can be improved with the use of some type of retaining structure.

13.1.1. Stabilize Cut Banks

Soil conditions, geomorphic activity, or being overly steep can cause a cut bank to become unstable. A retaining structure made of natural or synthetic materials will stabilize the cut bank and prevent debris from falling onto the trail bed.

13.1.2. Stabilize Trail Bed

Retaining structures are built along the outside edge of a trail bed when the slope supporting the bed has failed due to erosion, tree failure, or shallow landslide, and when moving the trail further into the hill slope is not an option. Without a retaining structure, achieving the designed trail width and stabilizing the trail bed is not possible.

13.1.3. Repair Stream Bank Erosion

A trail adjacent to a stream can suffer from destabilization due to lateral scour, changes in channel depth, and extremely high flows. Erosive forces of water within a stream, especially along the outside bank of a turn, can remove substantial amounts of material in a short period of time. A retaining wall is necessary to protect the trail alignment and stabilize the stream bank.

13.1.4. Minor Control Points

Minor control points, such as significant trees and rock outcroppings, often represent an abrupt grade change in excess of the maximum sustainable grade limit. If the trail alignment needs to go above or below this type of control point, a retaining wall across or through the control point will provide a linear grade that is within the designed grade standard. A retaining structure may also enable a trail designer to meet accessibility standards in these situations.

13.1.5. Minimizing Trail Bed Excavation and Back Slope Height

When constructing a trail on a steep side slope (in excess of 70%), a retaining wall can be constructed across the hill slope to minimize trail bed excavation and the height of the back slope. The retaining wall is constructed below the intended trail bed so the top of the wall represents the trail's outboard hinge and is at trail grade. This wall can then be backfilled with material imported from trail tread excavation leading to or away from the retaining wall. Because the trail bed is comprised of retained fill, the need for a cut bank is minimized or eliminated. This technique will eliminate or reduce the volume of material to be excavated from the steep hill slope and minimize or eliminate the need for a back slope

13.1.6. Foundations for Trail Structures

Trail structures such as bridges often require a retaining structure like an abutment to create a stable foundation. Often these structures are on or near a watercourse. A retaining structure can help resolve bank stabilization problems, bank elevation differences, midspan support requirements, and bridge freeboard requirements.

13.2. Advantages of Retaining Structures

Even though construction and maintenance of retaining structures may be costly, retaining structures provide solutions not possible with other methods of trail construction.

13.2.1. Maintain Existing Trail Alignment

Retaining structures can be used to keep an existing trail in its current alignment, or give the user access to unique features or vistas along the trail. For example, a waterfall may not be visible if the trail is rerouted to avoid the construction of a retaining structure.

13.2.2. Comply with Designed Trail Grade

The trail grade significantly influences the sustainability of the trail tread. Often a retaining structure is the only method to stay within the maximum sustainable grade that is identified during the design and layout process. In addition, the linear grade is also an important factor for users with mobility impairments. Standards for accessibility dictate the allowable linear grades and a retaining structure may be required to achieve those grades.

13.2.3. Protect Resources

A retaining structure is useful when constructing a trail through an area of sensitive cultural or natural resources. A retaining structure can significantly reduce the impacts of a trail by reducing the amount of excavation required to establish the trail bed. By retaining the trail bed fill on the downhill side of the trail, a retaining structure reduces the need to cut further into the uphill side of the trail. Aligning a trail through a rock outcrop can be accomplished with minimal excavation when a retaining structure is used. A retaining wall can also help protect tree roots when the trail crosses below a tree by containing the fill placed over the roots and maintaining the desired linear grade.

13.2.4. Reduce Debris on Trail

Raveling and small shallow debris slides are common when trails are constructed in areas with unstable soil or excessively steep slopes prone to instability. The debris that falls on the trail can cause impassable or hazardous situations. A retaining structure can buttress these slopes, effectively stabilize them, and reduce or stop soil and rocks from falling on the trail.

13.3. Disadvantages of Retaining Structures

Retaining structures do solve many construction and maintenance problems. However, the greater the number of trail structures that are built, the more expensive the trail will be, both in terms of initial construction and long-term maintenance. These issues should be considered prior to designing structures.

13.3.1. Expensive to Construct

Retaining structures cost more than a design solution that does not require a structure. Purchasing or gathering retaining structure materials, transporting materials to the worksite, preparing the site, and assembling the structure can result in substantial labor and material costs. If a sustainable trail route can be accomplished by excavating a trail bed, it is the most economical solution. However, economics should not be the only criteria in making this decision. Improving accessibility and enhancing the user experience must also be considered.

13.3.2. Potential Visual Impact

A retaining structure can detract from the user experience if conditions limit the choice of construction techniques and/or materials that can be used to those that don’t match the environment. For example, a wall can dominate the setting and draw the attention of the trail user away from the natural environment, especially if the materials used are not native to the setting. Keep in mind that trail users want to distance themselves from the built environment. Minimize the use of retaining structures and use native materials to smooth the transition from the built to the natural environment.

13.3.3. Long-Term Maintenance and Replacement Costs

Funds to construct trails are much easier to obtain than money to maintain them. This fact should be considered when planning a project that contains retaining structures. Be selective regarding construction materials and keep in mind the longevity of the materials as well as the aesthetics. A stone retaining structure may cost more, but the initial construction cost will be offset by the lower long-term maintenance cost.

13.4. Alternatives to Retaining Structures

Retaining structures do have disadvantages such as the initial construction cost, long-term maintenance and replacement costs, and visual impacts. If site conditions allow, use of a retaining wall can be avoided with some of the following alternatives. (See Chapter 11, *Principles of Trail Construction,* and Chapter 23, *Trail Maintenance Principles.*)

13.4.1. Reconstruct Trail into Bank

When the slope below the trail has failed and the trail bed has been compromised, move the trail alignment further into the hill slope. This option assumes the hill slope is stable enough to build into and the slope failure is a localized problem that will not migrate further into the hillside.

13.4.2. Reconstruct Trail Away from Unstable Area

When topography and landform conditions allow, reroute the existing trail away from an unstable area. Bypass the area by routing the trail around the unstable section and tie it back to the existing alignment. This method is recommended when the site of the failure is deep-seated and creates slumps and slides that affect the trail route. Even an extensive reroute may be the most cost effective and best long term solution to such a problematic area.

13.4.3. Re-contour Cut Bank and Re-vegetate Slopes

If an unstable cut bank causes debris to fall on the trail bed, re-contour and revegetate the cut bank instead of using a retaining structure. This method can only be implemented if the existing hill slope above the trail has a reduced percentage of slope (or grade break) a short distance above the trail. Then the cut bank can be re-contoured to meet the reduced slope above the grade break. (See Chapter 27, *Trail Removal and Site Restoration.)*

13.4.4. Construct Bridge or Viaduct

If conditions do not allow any of the previous options, then a bridge or viaduct may be used. The unstable area is spanned with a bridge and the soil contact points are limited to a few controlled and engineered locations. A bridge or viaduct is used when soil conditions are extremely unstable or the hill slope is very steep. Suitable abutment sites for the bridge structure are a critical requirement. This method is costly and labor-intensive, but may be the only solution for continued access along a trail. (See Chapter 16, *Trail Bridges.*)

13.5. Criteria for Selecting a Retaining Structure

The process for the selection of a retaining structure should include evaluation of the six criteria listed below. A comprehensive evaluation ensures a successful solution that can be built and maintained, blending with the natural environment while not overtaxing the project's resources or negatively impacting the environment. The structure must provide the most effective long-term solution and meet as many of the criteria discussed above as possible. The structure selection process should lead to one or more viable design solutions. Many types of retaining structures can be used in trail construction. This section looks at the most common retaining structures and identifies where and how they are used, and how they are constructed.

13.5.1. Logistics

When determining the type of retaining structure, project logistics are a key issue. The availability of native materials that can easily be gathered and transported to the construction site, the distance of the construction site to the nearest trailhead for transportation of non-native materials, and the difficulty of the terrain over which materials will be transported will have an effect on the other criteria and the project's success.

13.5.2. Aesthetics

Construction in the natural environment should always be hidden to the greatest extent possible. Trails are meant to facilitate intimate contact with the environment, and the eyes of the user should be on the natural setting and not on the trail or its structural components. A good trail structure compliments the natural setting rather than distracts from it. Using native stone, wood, soil, and vegetation in the design and concealing of retaining structures will enhance the aesthetic qualities of the trail and therefore the experience of the user. If non-native materials, such as synthetic cellular confinement systems, are the best design solution, cover them with soil and native vegetation so the structure will blend in with the natural environment.

13.5.3. Architectural Integration

Observe the existing historic, built elements in or near the project site. Some trails and trail systems have a distinct architectural flavor that is linked to an historic era or an overriding design that is prevalent throughout the geographical area. Note the materials used in structures and the construction techniques that define the carpentry or masonry styles. Duplicating a rock wall or unique details in a historic structure's carpentry ensures that the retaining structure will blend in with the existing setting.

13.5.4. Cost

There are many costs to consider when planning a retaining structure. Even when local, native construction materials are selected, the cost of gathering and transporting the materials to the worksite must be calculated. For non-native materials, the cost of purchasing and transporting the material to the trailhead and then to the actual worksite must be considered. In most cases, the labor to build the retaining structure will be the largest expense. Some retaining structure designs are easy to construct, but the materials are expensive. Other designs are difficult and time consuming to construct, but the materials are relatively inexpensive. There are also different life spans associated with each retaining structure design. Maintenance and replacement costs must also be considered.

13.5.5. Labor Source

The skill required to build a retaining structure must match the available labor source. A low skilled volunteer labor force should not be used to construct a highly technical structure. If low skilled labor is all that is available and extensive training is not affordable, the type of structure selected should match the skills of the crew.

13.5.6. Design Effectiveness

The best design solution can be difficult to determine. Different types of structures can effectively retain material, and each has strengths and weaknesses. A retaining structure may be simple to build, relatively cheap to construct, and blend in with the environment and architecture, but not be an effective solution to the problem. If it doesn't work, don't use it.

13.6. General Retaining Structure Design

The following design principles are typical for most types of retaining structures used in trail construction. Follow these simple yet important rules for more successful and sustainable trail structures.

13.6.1. Foundation

The foundation for any retaining structure must be excavated out of solid, stable, native material. The required depth and size of the foundation depends on the height and weight of the structure and the amount, weight, and slope of the material to be retained. The foundation should account for the weight of the material and the moisture in it from rain and snowmelt. Retaining structures require either a spread footing foundation or a pier system foundation, as determined by the style of structure and the sensitivity of the tree root systems in the project area. Any foundation constructed near a stream must be a minimum of 18 inches below the true scour line of the stream to prevent undermining by the stream flow. Check the actual scour depth of the stream channel. It may be below the observable depth if the section of stream being evaluated is unstable and in a depositional mode. Large, dynamic streams may require a foundation that is much deeper than 18 inches below the scour line. A retaining structure constructed within an active flood channel can also affect the stream's hydrology and morphology by changing flow dynamics. A qualified hydrologist or engineering geologist should be consulted when constructing a retaining structure within an active flood channel or stream that is unstable or has dynamic flows.

The foundation (excavation) for most multi-tier retaining structures should be level from side to side and uniformly smooth. If the structure is tilted to one side, the weight of the wall and backfill material will be distributed unevenly across the wall, which can lead to stress, shearing, and failures. The bottom of the foundation must also be tilted to the rear or back of the wall by a minimum of 5% to 10%. This “tilt back” helps transfer the weight of the retaining structure and its fill material into the hill slope. Without this subtle tilt, the weight of the structure and fill material is applied straight down and toward the front of the structure. The gravitational force of the weight can lead to premature failure of the retaining structure.

13.6.2. Wall Batter

As the height of the structure increases, a batter should be installed to move the face of the retaining structure back. The amount of batter varies according to the type and height of the structure being constructed. Multi-tiered walls over 3 feet in height require a minimum batter of 2 x 12 inches, (i.e., for every 12 inches of vertical rise, the face of the retaining structure steps back 2 inches) to reduce the pressure that the backfill material exerts on the front (“face”) of the structure. When prescribing a pre-manufactured multi-tier retaining structure, especially a structural wall or load-bearing wall, it is essential to consult with the manufacturer or a qualified licensed engineer.

13.6.3. Wall Anchoring Systems

Most retaining structure designs include some type of anchoring system to pull the front (“face”) or sides (“wings”) toward the back of the structure. With a log, split wood, or milled wood multi-tier structure, posts can be used to anchor the wall. These posts are installed so that the portion of the post that projects into the back of the structure is at a downward angle of 10%. The weight of the backfill once it is installed on top of the post forces the post down and toward the rear of the wall. In doing so, the post applies a force to the front and sides of the structure, pulling the front and sides of the structure toward the back. This force offsets any pressure being applied outward by the weight of the backfill. The same principle can be used with other types of retaining structures with anchoring systems.

13.6.4. Drainage Systems

A retaining structure must have openings or weep holes designed into the front and sides to allow water to drain from behind the structure. Fill material placed behind a retaining structure should be porous and well-draining to allow water to flow to these openings.

Drainage is necessary to prevent the buildup of pore pressure behind the structure that will exert excessive outward (active) pressure against the back of the structure's walls.

In addition to these features, a curtain drain or a drain lens can be used with retaining structures built into a hill slope to intercept water flowing from the hillside. Instead of weep holes, these structures can use a perforated pipe inside the drain lens to collect water that reaches the back of the structure and convey it to a suitable drainage discharge location. When using these types of drainage designs, a qualified engineer should be consulted.

13.7. Non-Structural Rock Retaining Walls

A non-structural rock retaining wall, sometimes referred to as "junk wall", is a simple retaining structure used to buttress the outboard hinge, the slope below the trail, or the cutbank of a trail. It is also used to frame in a drain lens, face a synthetic retaining wall, or provide rock slope protection along a streambank. Being non-structural, it is not intended to support or retain fill material used to bear a lot of users, heavy user groups such as equestrians, or structures such as bridge abutments.

The size of the rocks used to build a non-structural rock retaining wall is dependent on the wall's application. When used to frame in a drain lens, the rocks can range from 100 to 180 pounds. When used as rock slope protection on a streambank, the rocks can range between 200 pounds and 2,000 pounds, depending on the velocity, volume, and geomorphology of the stream.

The construction of a non-structural rock retaining wall begins with the excavation of a footing as described previously. The bottom of the footing should be level side to side and have a 5% tilt back. The largest rocks used in the structure are placed in the bottom tier to support the rocks above. The footing is shaped to accommodate the profile of the bottom of the rocks used in the first tier. There should be good contact between the sides of the rocks in the first tier. The second and succeeding tiers are placed further back into the hillslope so the face of the wall has a maximum of a one to one slope or 45 degrees. Each rock placed shall have a minimum of three points of contact with the rocks around it. See Photo 13.1 for an example of a non-structural retaining wall used to buttress a cut bank and a streambank.

Photo 13.1 - Non-Structural Rock Retaining Walls

13.8. Single Tier Log and Rock Structures

13.8.1. Applications

Single tier log and rock structures are the simplest retaining structures used in trail construction. They contain and support the outside edge of the trail, using fill material that is part of the trail bed. They may also contain fill material to bridge over tree roots and rocks or ramp on and off trail structures, and can be used to buttress the toe of a back slope for control of minor raveling or soil creep. Usually native logs and rocks from the clearing phase of trail construction or from close proximity to the project worksite are used for construction. A variety of non-native materials can also be used, such as pressure-treated lumber or concrete blocks, but the majority of single tier log and rock structures are built with on-site native materials. The logs should be rot-resistant to provide some longevity. Redwood or cedar work best, juniper and other species also have rot-resistant qualities.

13.8.2. Attributes

Single tier log and rock structures are relatively simple and do not require advanced trail building skills to construct. These structures are effective when used properly and have a substantial life span when rocks and rot-resistant logs are used. If on-site native materials from the clearing or trail bed excavation are used, these structures are inexpensive and blend in well with the surrounding environment. The single tier rock wall is easy to install with a curve, which is sometimes necessary and aesthetically more pleasing.

13.8.3. Limitations

Single tier structures are not intended to contain a large volume of backfill material. The required height of the retaining structure, the size of the logs and rocks available, the distance of the materials from the worksite, and the capability of the trail crew to move and place these materials all influence the size of a retaining structure. Using advanced rigging techniques, it is possible to move large redwood logs (5 to 7 feet in diameter) or large rocks (3 to 5 feet in diameter) for a single tier structure. Usually, the size, structural integrity, and movement and placement capability of construction materials limit single-tier structures to a height of 1 to 2 feet. Retaining structures are often misused in trail construction to minimize tread excavation by placing logs on the outside edge of the trail bed and using fill material to achieve the trail tread rather than excavating the trail bed out of the hillside. (See Chapter 11, *Principles of Trail Construction.*) This technique can result in poorly performing trail tread. Often logs used are not rot-resistant and are installed above trail grade, which results in trail bed failures when the logs rot out, or creates a berm that impedes overland water flow across the trail.

13.8.4. Construction

13.8.4.1. Single Tier Log Wall

Like most retaining structures, construction of a single tier log wall begins with the excavation of the foundation or footing. The location of the footing should be such that when the structure is completed, the distance from the inboard hinge of the trail to the outside edge of the structure provides the designed trail width. The elevation of the bottom of the footing should be set so that the top of the wall is lower than the outboard hinge of the trail. This elevation difference ensures that proper outslope is obtained and the wall does not impede the flow of water across the trail. (See Photo 13.2.) The footing should be large enough to support and secure the logs being placed into it. The depth of the footing should be a minimum of one-third of the height of the log. The bottom of the footing is shaped to accommodate the irregular shape of the logs. These materials must rest flush on the bottom of the trench to be fully supported, maintain their position, and contain the weight of the backfill. Place the logs in the footing by rolling them or by using timber carriers, Peaveys, cant hooks, rock bars, or simple rigging like direct pulls or choker rolls. (See Figure 13.1.) Like many trail construction tasks, using appropriate rigging techniques can improve worker efficiency, safety, and precision.

Secure logs in the footing by pinning them down with a minimum of two lengths of rebar. Gas powered drills or drill braces using ship augers can be used to drill the holes for the rebar. The diameter of the holes is usually 1/16-inch less than the 5/8-inch rebar so that the rebar fits tightly into the log. To control the drilling process and make sure that the drill bit is not damaged or dulled, drill the rebar holes prior to placing the log into the footing. The rebar should penetrate a minimum of 2 feet into the ground beyond the bottom of the log and is driven through the log with a double jack (sledge hammer). (See Figure 13.1.) Once this task is completed, the footing is backfilled with crushed rock and soil and the material is compacted in maximum 3-inch lifts.

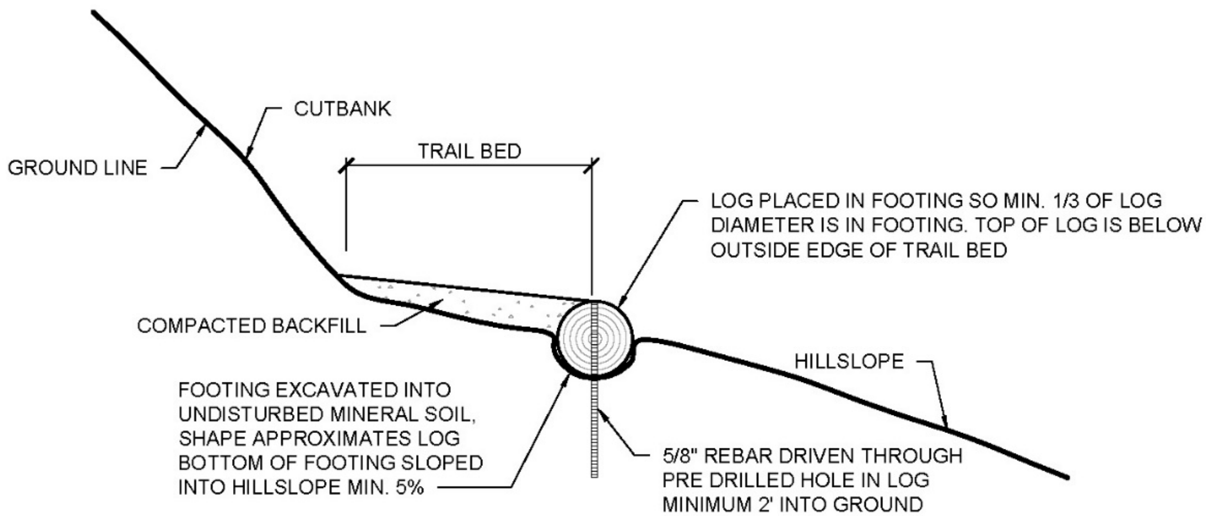
Photo 13.2 – Single Tier Log Wall

13.8.4.2. Single Tier Rock Wall

The initial layout and excavation of the footing for this type of retaining wall follow the same process described above for single tier log walls. The placement of rocks in the footing can be accomplished by carrying them by hand or in a rock litter, rolling them by hand, or using rock bars or simple rigging like a direct pull. Advanced rigging techniques such as high leads and skylines can also be used to place rocks in the footing.

If it is not possible to excavate a level footing, begin construction by placing rocks at the lowest point of the footing. Install the largest rocks first to serve as keystones to buttress the rest of the rocks. All the rocks should be placed so that their mass is on the inboard side of the footing (into the hill slope). This orientation, along with the 5% tilt back in the bottom of the footing, transfers their weight into the hill slope and prevents the rocks from rolling forward. Prior to placing rocks in the footing, the bottom of the footing can be further excavated and shaped so the finished elevation of the rock is level with the rock next to it. The bottoms of the rocks do not need to be flat, since the footing will be shaped to accommodate them, but the tops need to be reasonably flat as these faces serve as part of the trail bed.

SECTION VIEW



FRONT VIEW

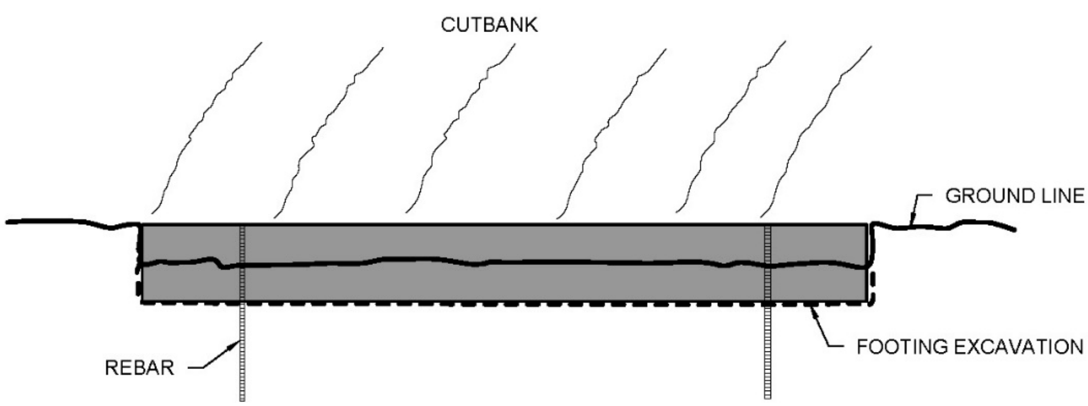


Figure 13.1 - Single Tier Log Walls

SINGLE TIER LOG WALLS

CALIFORNIA STATE PARKS

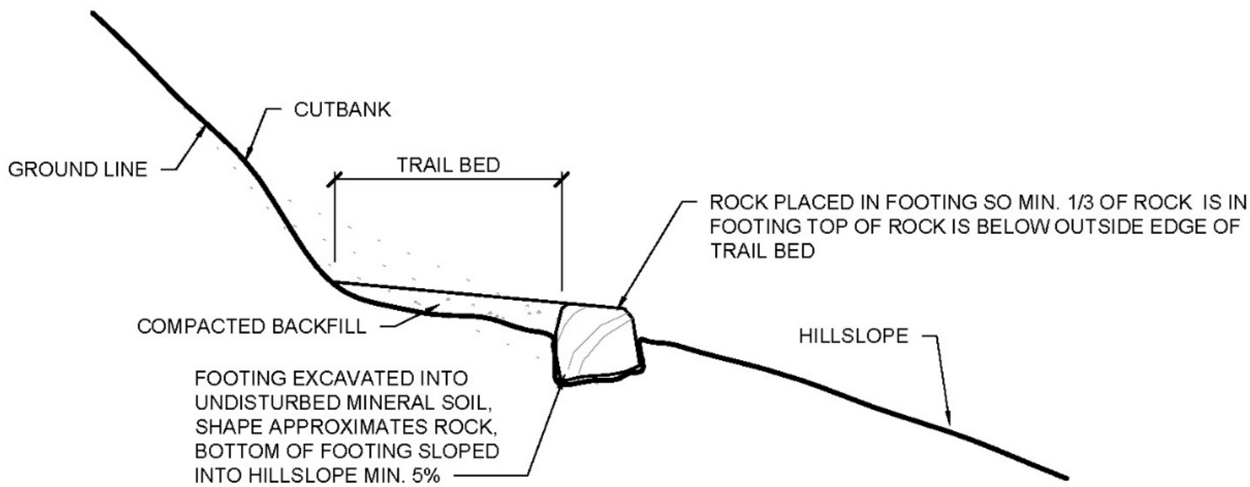
NOT TO SCALE

The sides of the rocks must be shaped so that they make good contact with the rocks next to them. Full contact along both sides of adjoining rocks is preferable, but if only limited contact can be accomplished, it must be toward the tops of the two rocks so the contact (friction) will lock the two rocks together and prevent them from rolling forward. (See Figure 13.2.)

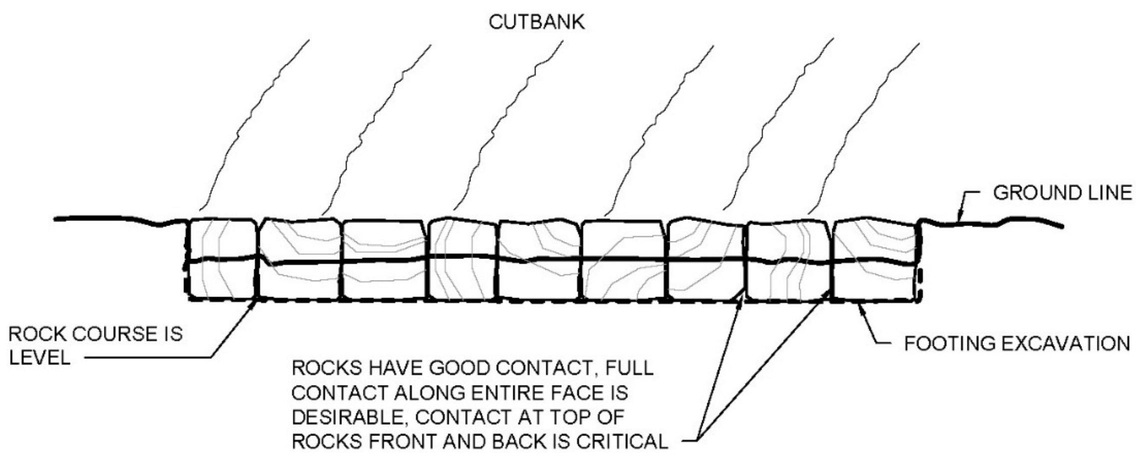
Once the rocks are in the footing, any gaps remaining between the rocks are filled by inserting small wedge-shaped rocks into the gaps ("chinking"). This process provides additional friction between the rocks and further locks them together. The addition of small rocks should be done carefully. Inserting too large of a rock into a gap can wedge the rocks apart. Chink the back of the wall first and then the front. Once this task is completed, the trench can be backfilled with crushed rock and soil and the material is compacted in maximum 3-inch lifts, similar to the log single tier retaining structure. (See Photo 13.3.)

Photo 13.3 – Single Tier Rock Wall

SECTION VIEW



FRONT VIEW



NOTE: IF THE FOOTING CANNOT BE EXCAVATED LEVEL THEN THE FIRST (LARGEST) ROCKS ARE PLACED AT THE LOWEST END OF THE FOOTING TO BUTTRESS THE WALL

Figure 13.2 - Single Tier Rock Walls

SINGLE TIER ROCK WALLS

CALIFORNIA STATE PARKS

NOT TO SCALE

13.9. Multi-Tier Interlocking Retaining Structures

13.9.1. Applications

A multi-tier interlocking retaining structure is complex to construct but can be used effectively to retain a fillslope, stabilize a back slope, retain fill used to bridge over tree roots and rocks, or serve as an abutment, mid-span support, and ramp for a bridge. It is commonly built in tiers comprised of facers, wings, and anchor posts. All components are interlocked through notching.

Like single tier retaining structures, multi-tier interlocking retaining structures are often built with on-site native materials for convenience and the cost savings of having construction materials close to the worksite. The construction materials are native logs, split products, or on-site milled lumber that are generated during clearing or gathered from near the worksite. In some cases, portable saw mills such as an Alaskan Mill or Mini Mill are set up on-site to mill lumber out of available downed logs. The logs for these structures should be rot-resistant. Redwood and cedar provide the best combination of longevity and structural quality. If logs are used for building materials, it is important that they be all heartwood, de-barked, and trimmed of all sapwood prior to use because bark and sapwood are more subject to insect infestation and rot. Split products should also be free of sapwood. Non-native materials can also be used, such as milled lumber, wood/plastic composites, or structural grade recycled plastic lumber.

13.9.2. Attributes

Multi-tiered, interlocking structures are very effective at retaining and containing fill. They can be used for almost any type of retaining structure and have the capacity to retain moderate amounts of fill. If using on-site native materials that are generated during the clearing phase of the project or within close proximity to the worksite, the building materials for these structures are comparatively inexpensive and can blend in well with the surrounding environment. Non-native materials such as plastic wood composites or structural grade recycled plastic wood are rot-resistant and should have a long life span.

13.9.3. Limitations

Construction of an interlocking structure requires trail workers that are skilled in layout and carpentry. These structures are labor intensive, and the life span of native building materials is relatively short when compared to the cost. Suitable materials are limited to specific trees and forest communities that are not prevalent. Non-native materials have longer life spans but are expensive and may have low aesthetic and cultural value. If effectively concealed, non-native materials can be cost effective. The logistics of moving logs, splitting lumber, milling lumber, or packing in non-native materials require a skilled labor force or a financial investment.

13.9.4. Construction

To effectively address the construction of multi-tiered interlocking retaining structures, they will be separated into two different categories: retaining walls and wooden cribbed abutments.

13.9.4.1. Multi-Tier Interlocking Retaining Wall

Multi-tier interlocking retaining walls are used to contain fill material below the trail or stabilize the hill slope above the trail. (See Photo 13.4.) A retaining wall can have several different configurations depending on the site conditions: a facer wall with anchor post; a facer wall and one wing wall with anchor post; and a facer wall with two wing walls and anchor post. A wing wall is required when the area to be retained is irregularly shaped and a straight wall will not adequately retain all of the unstable or backfill material. A wing wall may also be required if the retaining wall is being used to stabilize a stream bank and the wing wall is needed to prevent the current from flanking the front of the retaining wall. These walls can be constructed vertically or with a batter. Site conditions and the necessary wall height determine the style of wall to be built.

A multi-tier interlocking retaining wall begins with the excavation of a foundation as described in the section “Foundation and Wall Batter.” The foundation must be laid out so that the wall, which begins below the trail, will start far enough out from the outboard hinge. When it is finished, the top of the wall must terminate at or just below the outboard hinge of the trail. This layout must account for the overall height of the wall and the batter (if used). The elevation of the bottom of the foundation must also be on stable ground, so the combined height of the tiers (including the gaps between the facers) will equal the finished height of the outboard hinge of the trail. (See Figure 13.3.)

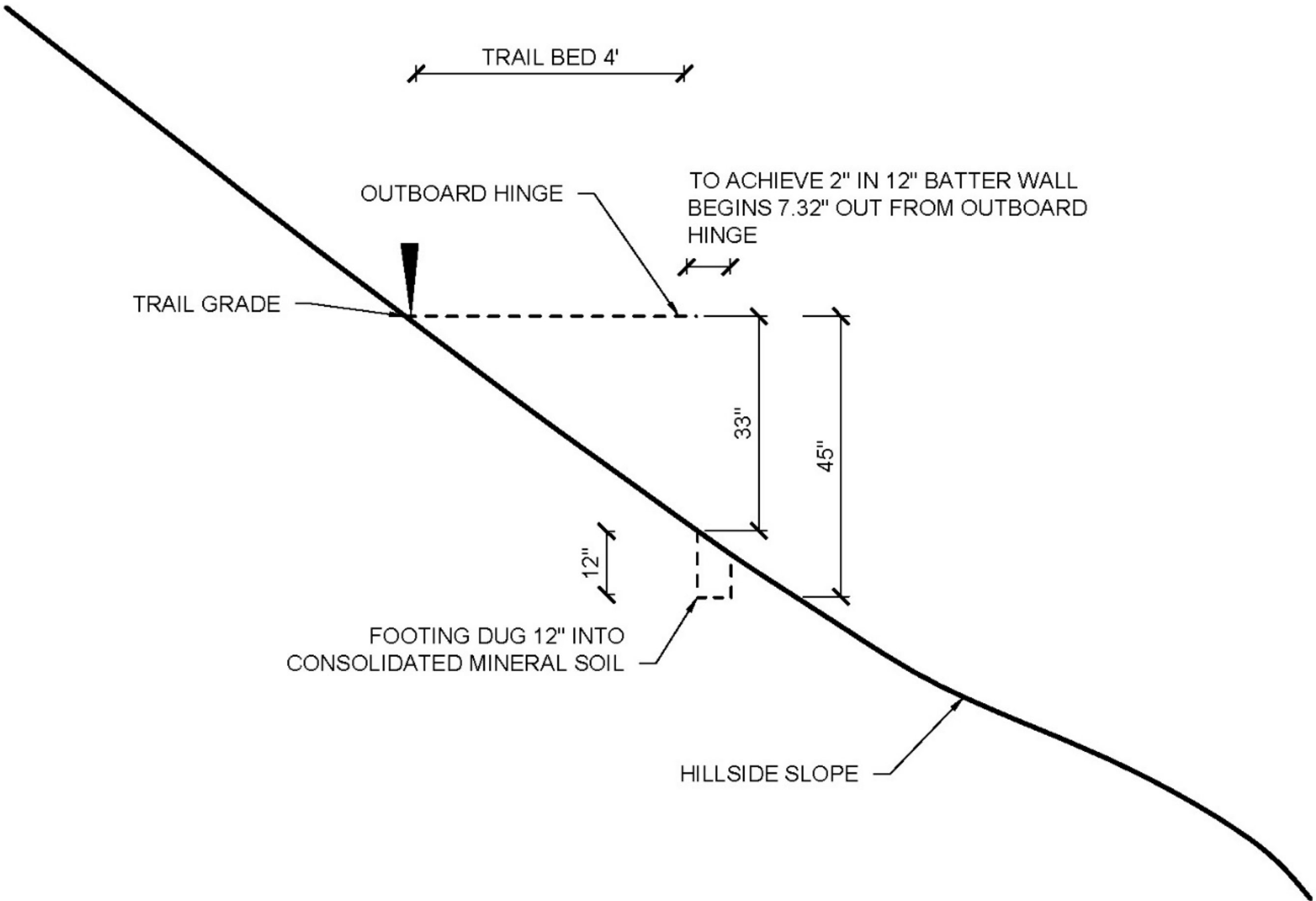
Each tier of a multi-tier retaining wall may consist of facers, wings, and anchor posts. On any tier, the anchor posts should not be spaced more than 8 feet apart horizontally. The length of the anchor posts should be a minimum of 48 inches. They are installed by digging a trench behind the wall to the necessary depth and length or burrowing the posts into the hill slope. (See Figure 13.4.) Where the length of the facer or wing wall is such that two or more facers or wings are spliced together, use a lap joint splice instead of a butt joint splice. Splices in the facers and wings are staggered between tiers so that the joints are not consecutive. Place anchor posts on each side of the splice to provide additional support. The anchor posts should not be more than 2 feet from the splice. Anchor posts should also be staggered and not placed directly above the preceding tier. Both ends of the retaining wall are keyed into native soil to prevent backfill from migrating around the outer edge of the wall.

When joining the facer and wing walls, the ends of the facer and wing wall members should extend beyond the notch a minimum of 6 inches to help lock the two members together. Anchor post ends also extend a minimum of 6 inches beyond the notch.

Photo 13.4 - Multi-Tier Interlocking Wooden Structure

A. Notching Layout

Prior to assembling the retaining wall, the dimensions of the material must be determined, along with notching and anchor post layout. The wings, facers, and anchor posts should be con heart redwood, cedar, or pressure treated Douglas fir, wood/plastic composite, or structural recycled plastic wood. In addition, for ease of handling and speed of production, the lumber should be a minimum of 4 inches wide and 8 inches high. If using logs, the minimum all-heart wood diameter is 8 inches at the small end. When using split products, it is not difficult to produce boards that approximate these dimensions. However, logs have a great deal of variance in their dimensions and a different layout process that will be addressed later. **Note the following calculations and measurements for laying out notches are based on using 4- x 8-inch lumber with uniform dimensions and installing the anchor posts at a 10% downward angle. If using lumber of different dimensions or installing the anchor posts at a downward angle other than 10%, the notching layout and depths will need to be recalculated using the mathematical processes described below.**



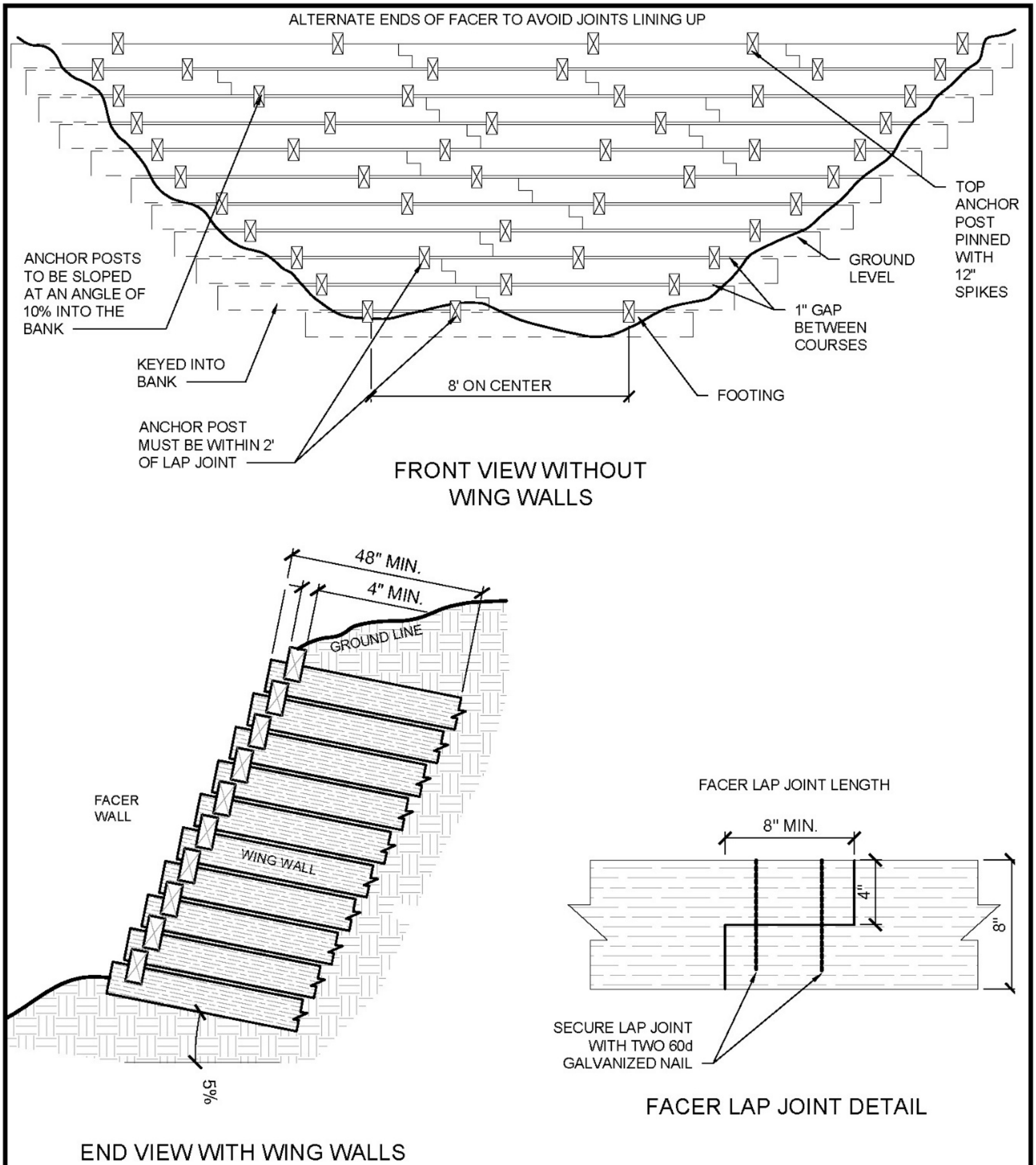
HEIGHT FROM TRAIL GRADE TO GROUND LEVEL IS 33"
HEIGHT OF FOOTING IS 12"
TOTAL HEIGHT OF WALL IS 45" FROM BOTTOM OF FOOTING TO OUTBOARD HINGE
USING 4"x8" DIMENSION LUMBER WITH A 1" GAP EACH COURSE IS 9" HIGH (BOTTOM COURSE IS ONLY 8" HIGH)
45" DIVIDED BY 9" = 5 COURSES REQUIRED FOR THE RETAINING WALL
45" - 1" (THERE IS NO 1" GAP AT THE BOTTOM OF THE WALL) = 44"
44" DIVIDED BY 12" = THE NUMBER OF 12" MULTIPLES IN THE WALL OR 3.66
MULTIPLY 3.66 BY 2" TO OBTAIN THE TOTAL BATTER FOR THE WALL OR 7.32"
DIVIDE 7.32" BY 4 (NUMBER OF HORIZONTAL OFFSETS SINCE THE BOTTOM COURSE DOES NOT HAVE A HORIZONTAL OFFSET) TO OBTAIN THE BATTER FOR EACH COURSE OR 1 13/16". THE NUMBER OF HORIZONTAL OFFSETS IS ALWAYS ONE LESS THAN THE TOTAL NUMBER OF COURSES.

Figure 13.3 - Multi-Tier Interlocking Structures Layout

MULTI-TIER INTERLOCKING STRUCTURES LAYOUT

CALIFORNIA STATE PARKS

NOT TO SCALE



NOTE: ALL FACER, WING, AND ANCHOR POST MEMBERS TO BE 4"x8" CON HEART REDWOOD, CEDAR, PRESSURE TREATED DOUGLAS FIR, OR STRUCTURAL PLASTIC WOOD.

Figure 13.4 - Multi-Tier Interlocking Structures Construction

MULTI-TIER INTERLOCKING STRUCTURES CONSTRUCTION

CALIFORNIA STATE PARKS

NOT TO SCALE

Assuming the material for the facers, wings, and anchor posts are nominal (full dimension) 4- x 8-inch milled redwood and the height of the wall from the bottom of the foundation to the top of the outboard hinge is 45 inches, it will take five facer boards to obtain the necessary height of the wall, including the four 1-inch gaps between the boards (45 in. height ÷ (8 in. board + 1 in. space) = 5). (See Figure 13.3.) Since the bottom board does not have a 1-inch gap, the wall height with five boards will only be 44 inches. This discrepancy can be resolved by reducing the depth of the footing by 1 inch or lowering the trail grade elevation by 1 inch to achieve the correct wall height.

B. Notching Facers and Wing Walls

The next step is to determine the notching pattern. To notch two facers and one wing (4- x 8-inch boards) tightly together, each board needs to be notched to a depth of 2 inches, which requires notching the top of the bottom facer 2 inches, the bottom of the wing 2 inches, the top of the wing 2 inches, and the bottom of the top facer 2 inches (four notches). However, to obtain a 1 inch gap between the two facers and the wing, each notch must be reduced by 1/4 inch (4 x 1/4 in. = 1-inch gap). The final notch depth is 1 3/4 inches. (See Figure 13.5.) The notches are made level so the facers and wings are level to each other. If surfaced (S4S) lumber is used (actual dimensions are 3 1/2 inches x 7 1/2 inches), the notching depth is 1 5/8 inches to compensate for the 1/2 inch difference in board height.

C. Notching the Anchor Post

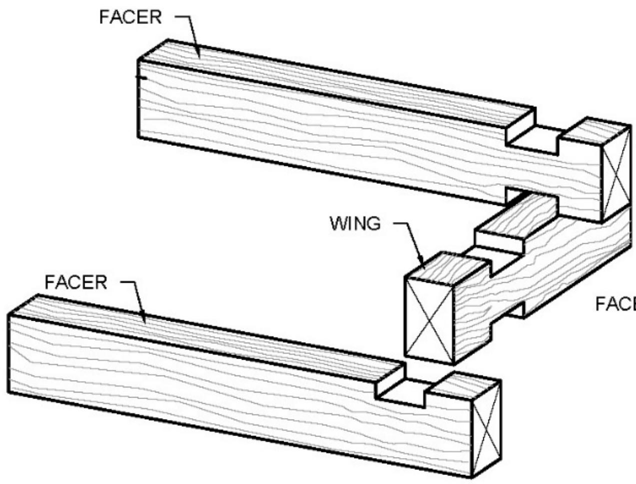
Anchor posts are notched into the facers and wings at a 10% downward angle toward the rear of the wall. To achieve this downward angle, the notching layout for the 4- x 8-inch anchor post is determined next. This structural member also needs to maintain the 1-inch gap between the facers for drainage. **To simplify this discussion, the notching between the facer and the anchor post will be used as an example. The notching between the wing and the anchor post is identical.**

D. Vertical Wall Notching Layout (Facers and Wings)

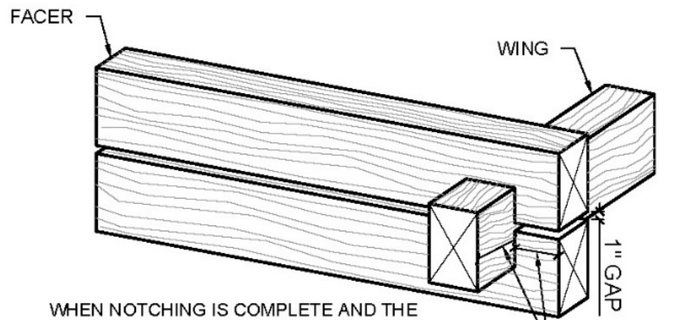
With a full dimension 4- x 8-inch wing lying on its side, measure in from the top left corner 6 inches (A) and 10 inches (B) and scribe small reference marks at those locations. (See Figure 13.5.) Next, measure in from the bottom left corner 6 inches (A) and 10 inches (B) and scribe small reference marks at those locations. Then, from the top of the board, measure down at a right angle from the 6- and 10-inch reference marks 1 3/4 inches (C) and scribe small reference marks. Then scribe vertical lines between those two marks and draw a horizontal line connecting those two lines. Next, from the bottom of the board, measure up at a right angle from the 6- and 10-inch reference marks 1 3/4 inches (C) and scribe small reference marks. Then scribe vertical lines between those two marks. Draw a horizontal line connecting those two lines. (See Figure 13.5.) Repeat this layout on the opposite side of the wing. Next, draw lines across the top and bottom of the wing connecting the 6- and 10-inch marks. The area within these lines is then removed.

With the facer lying on its side, measure in from the end of the facer (top left corner) 6 inches (A) and 10 inches (B) and scribe small reference marks at those locations. Then from the top of the board measure down at a right angle from the 6- and the 10-inch reference marks 1 3/4 inches (C) and scribe small reference marks. (See Figure 13.5.) Then scribe vertical lines between those two marks and draw a horizontal line connecting those two lines. Repeat this layout on the opposite side of the facer. Next, draw lines across the top of the facer connecting the 6- and 10-inch marks. The area within these lines is then removed.

E. Vertical Wall Notching Layout (Facers and Anchor Posts)
Since the notch is located on the 4-inch dimension of the 4- x 8-inch board, calculate 10% of 4 inches to determine the notching layout. First, convert the 4-inch measurement to 1/16 of an inch (e.g., 4 x 16/16 = 64/16.) This calculation is necessary to convert a percentage of an inch into a fraction of an inch. Standard tape measures are in increments of inches and fractions of an inch with 1/16 of an inch being the smallest fraction. Then, multiply the number of 1/16ths of an inch by 10% (e.g., 0.10 x 64/16 = 6.4/16 in.). Round up this number to 7/16 inch to ensure the downward angle is 10% or greater. This 7/16-inch taper will be split between the adjoining faces of the facer and anchor post, so once notched, they fit tightly together with no gaps (7/16 ÷ 2 = 3.5/16). Since the smallest fraction being used is 1/16 of an inch, round up again to 4/16 of an inch. Based on these calculations, the notches between the top of the facer and the bottom of the anchor post needs to be 4/16 or 1/4 of an inch lower in the back than the front to obtain a 10% downward angle for the anchor post. The top of the facer is notched 1 1/2 inches in the front and 1 3/4 inches in the back, and the bottom of the anchor post is notched 1 1/2 inches at the front and 1 3/4 inches in the back. To keep the top of the next facer level and eliminate a gap between the two faces, the taper of the notch between the top of the anchor post and the bottom of the next facer is reversed. The top of the anchor post is notched 1 3/4 inches in the front and 1 1/2 inches in the back, and the bottom of the facer (installed on top of the anchor post) is notched 2 1/8 inches in the front and 1 7/8 inches in the back. The depth of the notch on the bottom of the facer is increased to compensate for the acute angle of the anchor post. The top of the anchor post projects above the elevation of the other wall members and a deeper notch on the bottom of the facer is required to provide the 1-inch gap and keep the top of the facer level. This layout provides the 1-inch drainage gap, the minimum 10% downward angle for the anchor post, and a flush fitting notch. (See Figures 13.6) If surfaced (S4S) lumber is used, refer to the notching depths listed in the table in Figure 13.6.

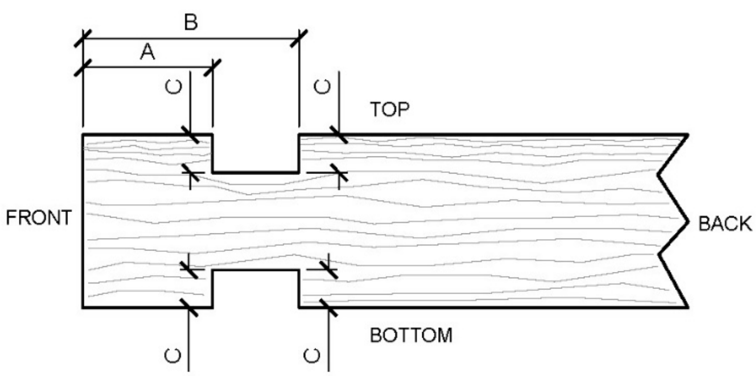


WHEN NOTCHING A WING INTO TWO FACERS THE MEMBERS ARE NOTCHED TO KEEP THE COURSES LEVEL. THE DEPTH OF EACH NOTCH IS 1/4" LESS THAN ONE FOURTH OF THE HEIGHT OF THE FACER AND WING. FOR FULL DIMENSION LUMBER, THE TOP NOTCH OF A WING IS 1 3/4", THE BOTTOM NOTCH OF A FACER IS 1 3/4". LAYOUT NOTCHES SO A MINIMUM OF 6" OF THE FACER AND WING MEMBER EXTENDS BEYOND THE NOTCH.



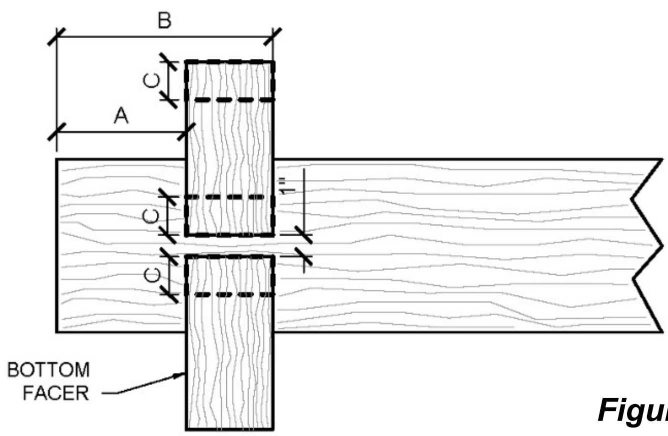
WHEN NOTCHING IS COMPLETE AND THE FACER AND WING ARE FIT TOGETHER THERE WILL BE A 1" GAP BETWEEN THE TWO FACERS AND A MINIMUM 6" OVERHANG BEYOND THE NOTCH ON THE FACERS AND THE WINGS.

WING AND FACER NOTCHING DETAIL SIDE VIEW



	FULL DIMENSION	SURFACED
A	6"	6"
B	10"	9-1/2"
C	1-3/4"	1-5/8"

WING & FACER NOTCHING DETAIL SIDE VIEW ASSEMBLED



NOTE: ALL FACER, WING, AND ANCHOR POST MEMBERS TO BE 4"x8" CON HEART REDWOOD, CEDAR, PRESSURE TREATED DOUGLAS FIR, OR STRUCTURAL PLASTIC WOOD.

Figure 13.5 - Vertical Wall Notching (Wing Wall)

VERTICAL WALL NOTCHING (WING WALL)

CALIFORNIA STATE PARKS

NOT TO SCALE

With a full dimension 4- x 8-inch anchor post lying on its side, measure in from the top left corner 6 inches (A) and 10 inches (B), and scribe small reference marks at those locations. Next, measure in from the bottom left corner 6 13/16 inches (C) and 10 13/16 inches (D) and scribe small reference marks at those locations. (See Figure 13.6) Next, scribe lines across the side of the anchor post connecting the 6-inch mark to the 6 13/16-inch mark and the 10-inch mark to the 10 13/16-inch mark. (See Figure 13.6.) Then, from the top of the board measure down at a right angle from the 6 inch reference mark 1 3/4 inches (E) and scribe a small reference mark. Then, measure down at a right angle from the 10-inch reference mark 1 1/2 inches (F) and scribe a small reference mark. Draw a horizontal line connecting those two marks. Next, from the bottom of the board, measure up at a right angle from the 6 13/16-inch reference mark 1 1/2 inches (G) and scribe a small reference mark. Then, measure up at a right angle from the 10 13/16-inch reference mark 1 3/4 inches (H) and scribe a small reference mark. Draw a horizontal line connecting those two marks. (See Figure 13.6) Repeat this layout on the opposite side of the anchor post. Next, draw lines across the top and bottom of the anchor post connecting the measurements of equal distance located at the 6-, 10-, 6 13/16-, and 10 13/16-inch marks. The area within these lines is then removed.

The bottom of the second facer, placed on top of the anchor post, is notched in alignment with the anchor post. This location can be determined by measuring from the end of the bottom facer to the anchor post or by laying the second facer across the top of the anchor post in alignment with the bottom facer and scribing two lines coinciding with the outside edges of the anchor post. Flip the board upside down and use a square to finish scribing the two lines across the bottom of the facer. To manage the notching layout, mark the top of the facer with a T, the bottom with a B, the front with an F, and the back with a B. Next, measure down at a right angle from the two lines on the front side of the board 2 1/8 inches and scribe a small reference mark. Using a square, scribe two right angle lines from the lines scribed across the top of the board to the two 2 1/8-inch reference marks. Then draw a horizontal line connecting those two 2 1/8 inch marks. Repeat this layout on the back side of the facer but scribe down 1 7/8 inches instead of 2 1/8 inches. This layout reverses the anchor post notches to provide a tight fitting notch and a level facer. The area within these lines is then removed. If another tier is constructed above this facer, the top of this facer is laid out and notched the same as the top of the first facer. (See Figure 13.6.)

F. Battered Wall Notching Layout

If the wall has a batter, divide the height of the wall by 12 inches to determine the total batter. For example, in Figure 13.3 the total batter for the wall with a 2-inch in 12-inch batter is calculated as follows: 44 (total wall height) ÷ 12 = 3.66 (number of 12-inch vertical rises). Multiply 3.66 by 2 inches to obtain the total batter for the wall (7.32 inches). Divide 7.32 inches by 4 (the number of courses minus the bottom course, which will have no batter) to obtain the batter for each course (7.32 ÷ 4 = 1.83 inches of batter per course). Convert 1.83 inches into fractions of an inch by multiplying it by 16, the number of 1/16th in an inch (1.83 in. x 16 = 29/16 in. or 1 13/16 in.). Each course above the bottom course will start 1 13/16 inches inward of the course below it to achieve the 2-inch in 12-inch batter. (See Figure 13.3.)

The notching layouts for the top of the facer and the bottoms of the anchor post and wing are identical to a vertical wall. However, the notches for the top of the anchor post and the wings are set back 1 13/16 inches to achieve the appropriate batter. (See Figure 13.7.)

G. Battered Wall Notching Layout (Facers and Wings)
With a full dimension 4- x 8-inch wing lying on its side, measure in from the top left corner 7 13/16 inches (A) and 11 13/16 inches (B) and scribe small reference lines at those locations. (See Figure 13.7.) Next, measure in from the bottom left corner 6 inches (C) and 10 inches (D) and scribe small reference marks at those locations. Then, from the top of the board, measure down at a right angle from the 7 13/16- and 11 13/16-inch reference marks 1 3/4 inches (E) and scribe small reference marks. Scribe vertical lines between those two marks and draw a horizontal line connecting those two lines. Next, from the bottom of the board, measure up at a right angle from the 6 inch and 10-inch reference marks 1 3/4 inches (E) and scribe small reference marks. Scribe vertical lines between those two marks and draw a horizontal line connecting those two lines. (See Figure 13.7.) Repeat this layout on the opposite side of the wing. Next, draw lines across the top of the wing connecting the 7 13/16-and 11 13/16-inch marks and across the bottom of the wing connecting the 6- and 10-inch marks. The area within these lines is then removed.

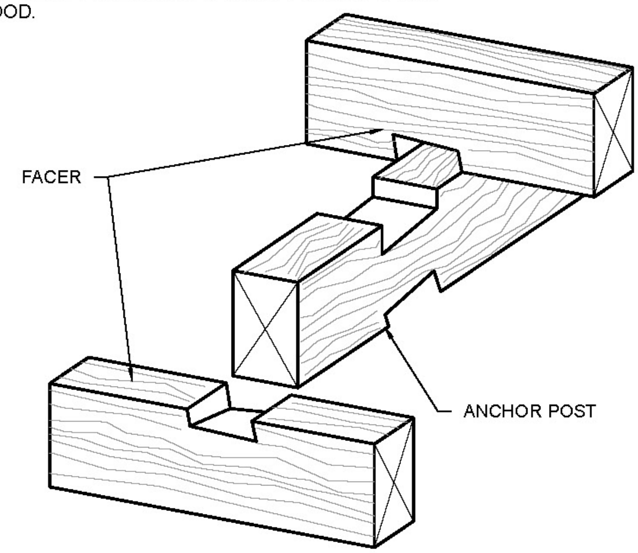
H. Battered Wall Notching Layout (Facers and Anchor Posts)
With a full dimension 4- x 8-inch anchor post lying on its side, measure in from the top left corner 6 inches (A), 7 13/16 inches (B), 10 inches (C), and 11 13/16 inches (D) and scribe small reference lines at those locations. Next, measure in from the bottom left corner 6 13/16 inches (E), 8 10/16 inches (F), 10 13/16 inches (G), and 12 10/16 (H) inches and scribe small reference marks at those locations. (See Figure 13.8.) Scribe lines across the side of the anchor post connecting the 6-inch mark to the 6 13/16-inch mark, the 7 13/16-inch mark to the 8 10/16-inch mark, the 10-inch mark to the 10 13/16-inch mark, and the 11 13/16-inch mark to the 12 10/16-inch mark. (See Figure 13.8.) Next, from the top of the board, measure down at a right angle from the 7 13/16-inch reference mark 1 3/4 inches (I) and scribe a small reference mark. Then, measure down at a right angle from the 11 13/16-inch reference mark 1 1/2 inches (J) and scribe a small reference mark. Draw a line connecting those two marks. Next, from the bottom of the board, measure up at a right angle from the 6 13/16-inch reference mark 1 1/2 inches (K) and scribe a small reference mark. Then, measure up at a right angle from the 10 13/16-inch reference mark 1 3/4 inches (L) and scribe a small reference mark. Draw a line connecting those two marks. (See Figure 13.8.) Repeat this layout on the opposite side of the anchor post. Draw lines

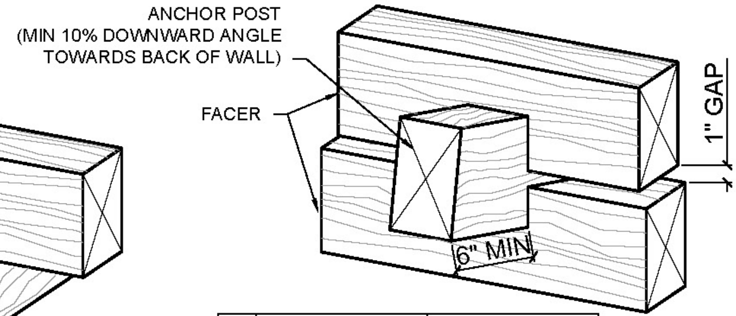
across the top of the anchor post connecting the 7 13/16-inch and11 13/16-inch marks and across the bottom connecting the 6 13/16-inch and 10 13/16-inch marks. There are now eight lines outlining the upper and lower notches. The area within these lines is then removed.

An alternative to this layout method is to use a framing square to layout the notches, which reduces the number of diagonal lines and keeps the layout less confusing. With the anchor post lying on its side, from the top left corner scribe the 6-inch (A), 7 13/16-inch (B), 10-inch (C), and 11 13/16-inch (D) marks along the top of the anchor post. (See Figure 13.9.) Then place the framing square along the bottom of the board so the 1-inch line on the inside of the tongue and the 10 inch line on the inside of the body are even with the bottom of the board. Slide the square in this position to where the inside of the tongue lines up with the 6-inch mark. Scribe a diagonal line approximately 2 1/2 inches long along the inside of the tongue at the bottom of the board. Then, slide the square to the 7 13/16-inch line and scribe a 2 1/2-inch line along the inside of the tongue at the top of the board. Next, slide the square to the 10-inch line and scribe a 2 1/2-inch line along the inside of the tongue at the bottom of the board. Then, slide the square to the 11 13/16-inch line and scribe a 2 1/2 inch line along the inside of the tongue at the top of the board. After all four diagonal lines are scribed measure down from the 7 13/16-inch mark by 1 3/4 inches (E) and scribe a small reference mark. Then, measure down from the 11 13/16-inch mark by 1 1/2 (F) inches and scribe a small reference mark. Next, measure up from the bottom of the board at the 6-inch diagonal line by 1 1/2 inches (G) and scribe a small reference mark. Then, measure up from the bottom of the board at the 10-inch diagonal line by 1 3/4 inches (H) and scribe a small reference mark. Scribe a line connecting the 1 1/2- and 1 3/4-inch marks. Repeat this layout on the opposite side of the post and transcribe the lines across the top and bottom of the anchor post. **This framing square layout method can also be used on the anchor post notching layout for vertical walls.**

Cutting out notches in the facers, wings, and anchor posts can be done with hand or power tools, depending on project logistics, restrictions on use of power tools, and the capabilities of the labor force. For hand tools, once the notch is scribed (the lines across the top and bottom of the board, the two outside lines, and the bottom lines on the front and back of the board), use a crosscut handsaw to cut along the top line and the outer lines to the depth of the notch. To help remove the material within the notch, make additional cuts to the same depth inside of the two outside lines. These cuts should be spaced 1/2 to 3/4 inch apart. Recycled plastic, wood composites, and wood with an uneven cross grain require saw cuts with close spacing to help control the removal of material in the notch.

NOTE: ALL FACER, WING, AND ANCHOR POST MEMBERS TO BE 4"x8" CON HEART REDWOOD, CEDAR, PRESSURE TREATED DOUGLAS FIR, OR STRUCTURAL PLASTIC WOOD.

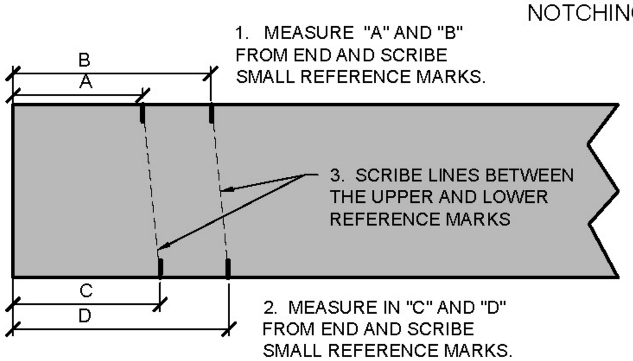




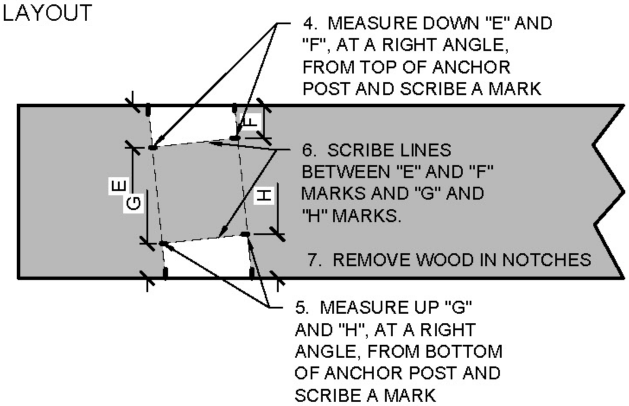
	FULL DIMENSION	SURFACED
A	6"	6"
B	10"	9-1/2""
C	6-13/16"	6-3/4"
D	10-13/16	10-1/4"
E	1-3/4"	1-5/8"
F	1-1/2"	1-7/16"
G	1-1/2"	1-7/16"
H	1-3/4"	1-5/8"
I	1-1/2"	1-7/16"
J	1-3/4"	1-5/8"
K	2-1/8"	2"
L	1-7/8"	1-13/16"

WHEN NOTCHING AN ANCHOR POST INTO TWO FACERS THE MEMBERS ARE NOTCHED AT A 10% DOWNWARD ANGLE. LAYOUT NOTCHES SO A MINIMUM OF 6" OF THE ANCHOR POST EXTENDS BEYOND THE NOTCH.

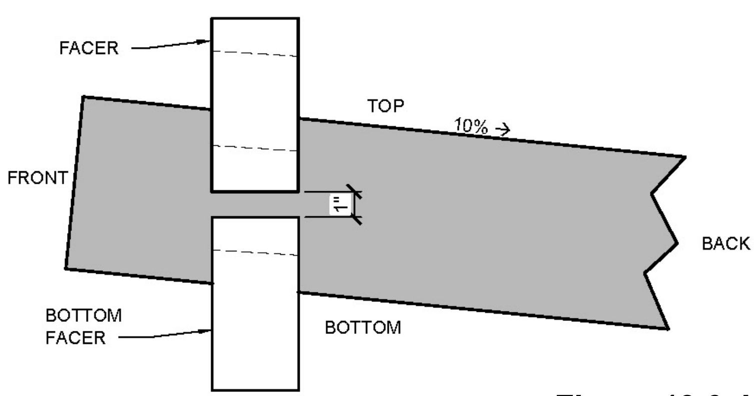
NOTCHING LAYOUT



ANCHOR POST NOTCHING DETAIL WITH FACERS SIDE VIEW



FACER NOTCHING DETAIL END VIEW



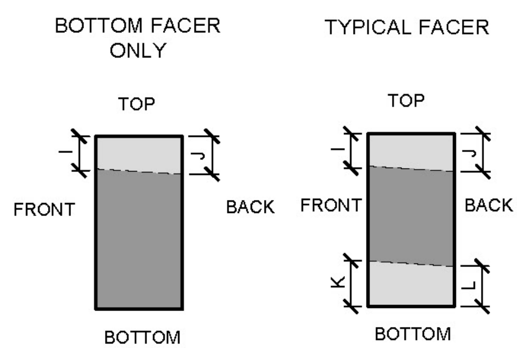
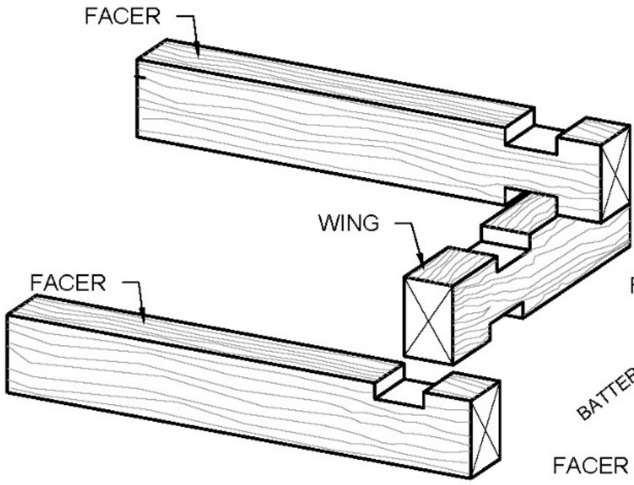


Figure 13.6 -Vertical Wall Notching (Anchor Post)

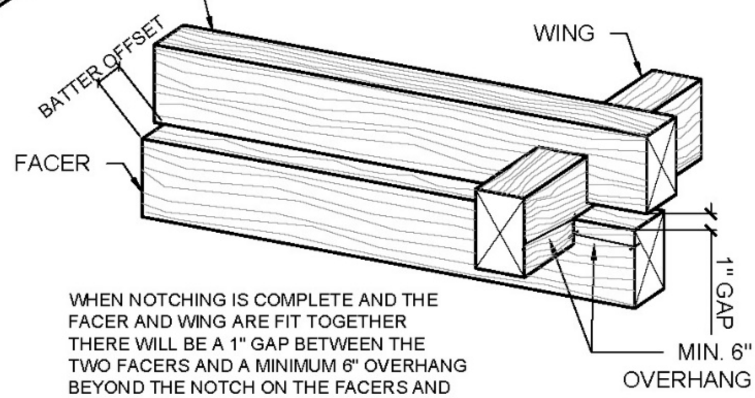
VERTICAL WALL NOTCHING (ANCHOR POST)

CALIFORNIA STATE PARKS

NOT TO SCALE

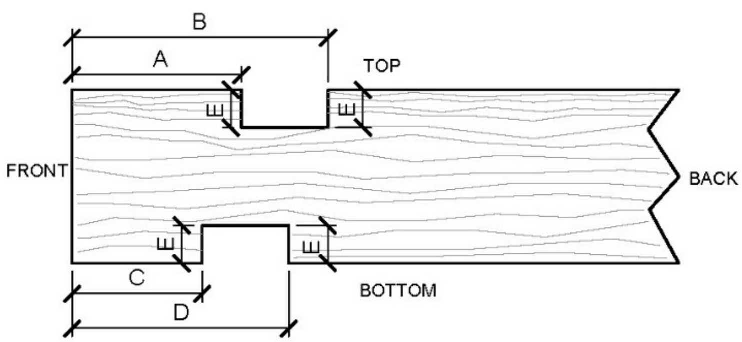


WHEN NOTCHING A WING INTO TWO FACERS THE MEMBERS ARE NOTCHED TO KEEP THE COURSES LEVEL. THE DEPTH OF EACH NOTCH IS 1/4" LESS THAN ONE FOURTH OF THE HEIGHT OF THE FACER AND WING. FOR FULL DIMENSION LUMBER, THE TOP NOTCH OF A WING IS 1 3/4", THE BOTTOM NOTCH OF A FACER IS 1 3/4". LAYOUT NOTCHES SO A MINIMUM OF 6" OF THE FACER AND WING MEMBER EXTENDS BEYOND THE NOTCH.



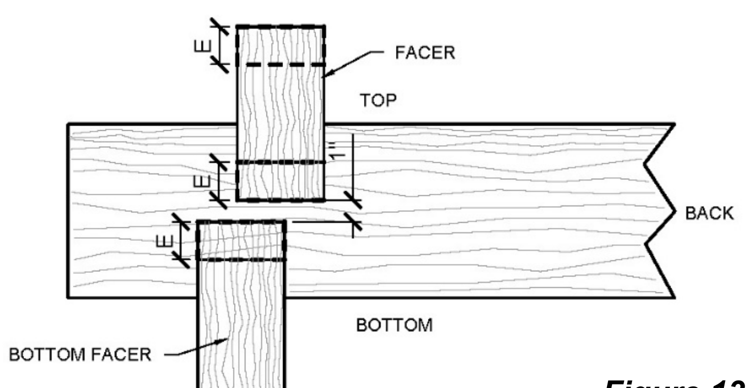
WHEN NOTCHING IS COMPLETE AND THE FACER AND WING ARE FIT TOGETHER THERE WILL BE A 1" GAP BETWEEN THE TWO FACERS AND A MINIMUM 6" OVERHANG BEYOND THE NOTCH ON THE FACERS AND THE WINGS.

WING NOTCHING DETAIL SIDE VIEW



	FULL DIMENSION	SURFACED
A	7-13/16"	7-13/16"
B	11-13/16	11-5/16"
C	6"	6"
D	10"	9-1/2"
E	1-3/4"	1-5/8"

WING & FACER NOTCHING DETAIL



NOTE: ALL FACER, WING, AND ANCHOR POST MEMBERS TO BE 4"x8" CON HEART REDWOOD, CEDAR, PRESSURE TREATED DOUGLAS FIR, OR STRUCTURAL PLASTIC WOOD.

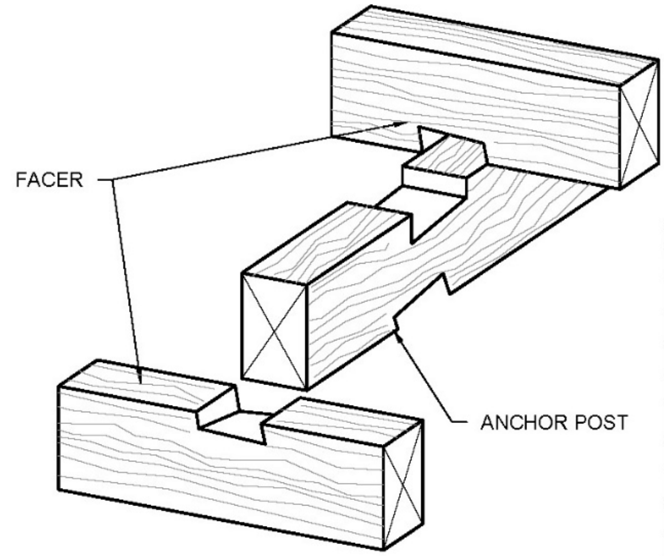
Figure 13.7 - Battered Wall Notching (Wing Wall)

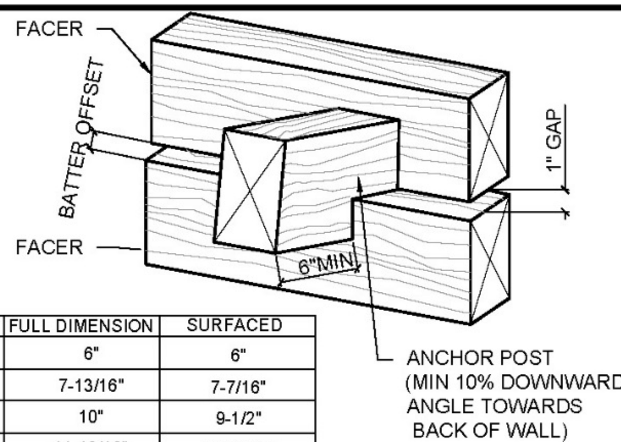
BATTERED WALL NOTCHING (WING WALL)

CALIFORNIA STATE PARKS

NOT TO SCALE

NOTE: ALL FACER, WING, AND ANCHOR POST MEMBERS TO BE 4"x8" CON HEART REDWOOD, CEDAR, PRESSURE TREATED DOUGLAS FIR, OR STRUCTURAL PLASTIC WOOD.

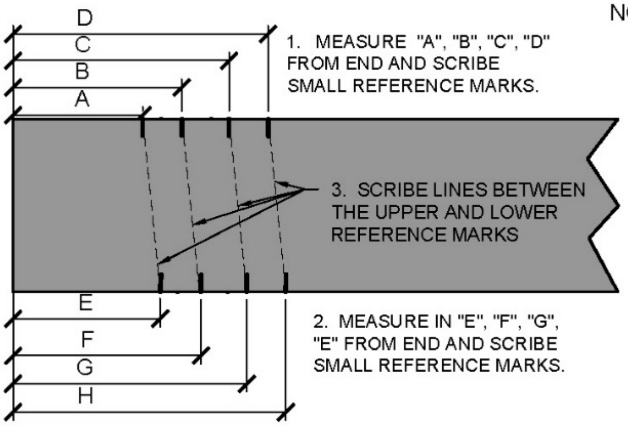




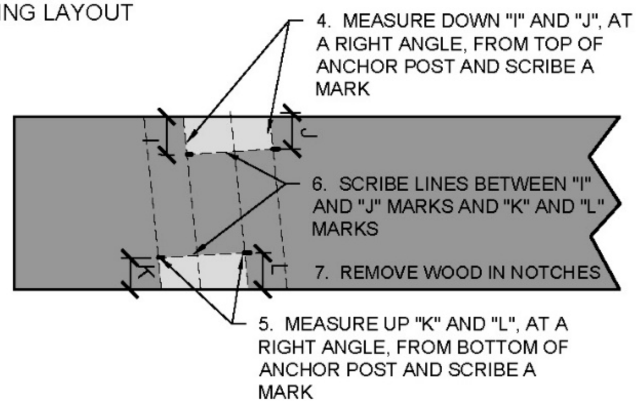
WHEN NOTCHING AN ANCHOR POST INTO TWO FACERS THE MEMBERS ARE NOTCHED AT A 10% DOWNWARD ANGLE. LAYOUT NOTCHES SO A MINIMUM OF 6" OF THE ANCHOR POST EXTENDS BEYOND THE NOTCH.

	FULL DIMENSION	SURFACED
A	6"	6"
B	7-13/16"	7-7/16"
C	10"	9-1/2"
D	11-13/16"	10-15/16"
E	6-13/16"	6-3/4"
F	8-10/16"	8 3/16"
G	10 13/16""	10-1/4"
H	12-10/16"	11-11/16"
I	1-3/4"	1-7/16"
J	1-1/2"	1-7/16"
K	1-1/2"	1-7/16"
L	1-3/4"	1 5/8"
M	1-1/2"	1-7/16"
N	1-3/4"	1-5/8"
O	2-1/8"	2"
P	1-7/8"	1-13/16"

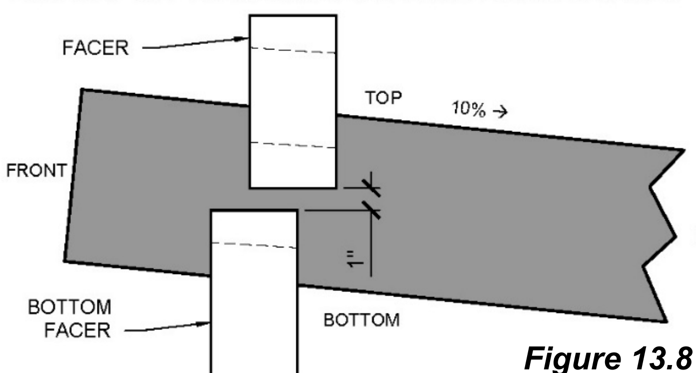
NOTCHING LAYOUT



ANCHOR POST NOTCHING DETAIL WITH FACERS SIDE VIEW



FACER NOTCHING DETAIL END VIEW



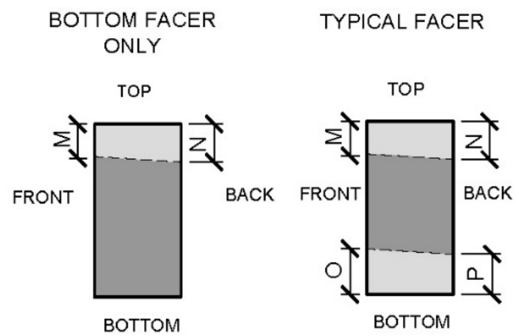


Figure 13.8 - Battered Wall Notching (Anchor Post)

BATTERED WALL NOTCHING (ANCHOR POST)

CALIFORNIA STATE PARKS

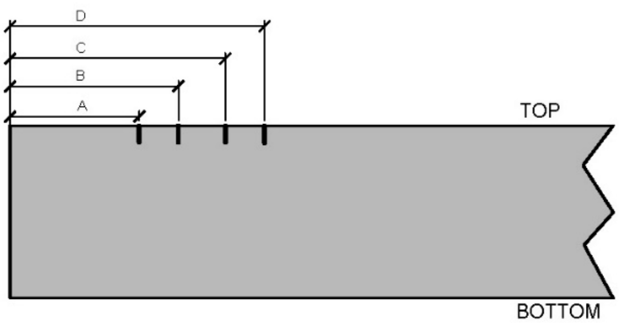
NOT TO SCALE

NOTE: ALL FACER, WING, AND ANCHOR POST MEMBERS TO BE 4"x8" CON HEART REDWOOD, CEDAR, PRESSURE TREATED DOUGLAS FIR, OR STRUCTURAL PLASTIC WOOD.

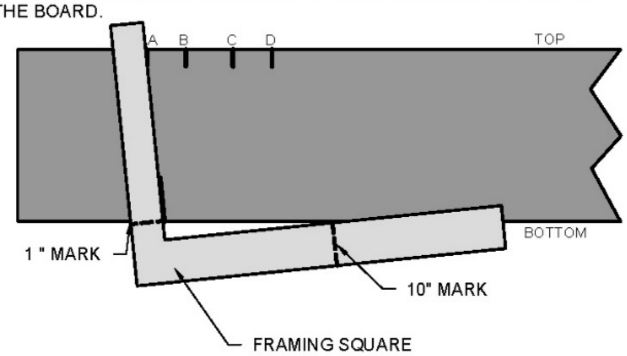
THIS DETAIL SHOWS THE NOTCHING FOR AN ANCHOR POST USED FOR A WALL WITH BATTER AS AN EXAMPLE OF ANCHOR POST LAYOUT WITH A FRAMING SQUARE

NOTCHING LAYOUT

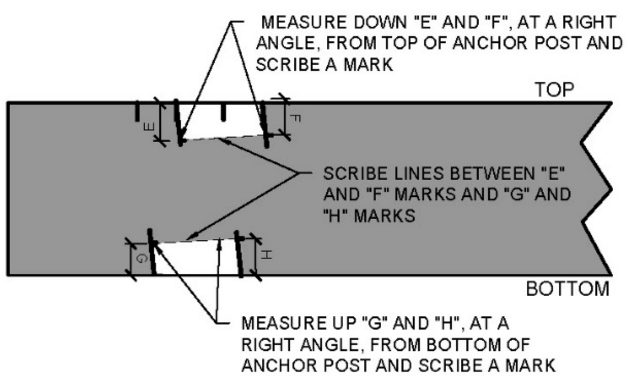
1. MEASURE "A", "B", "C", "D" FROM END AND SCRIBE SMALL REFERENCE MARKS.



2. PLACE THE FRAMING SQUARE ALONG THE BOTTOM OF THE BOARD SO THE 1" LINE IS ON THE INSIDE OF THE TONGUE AND THE 10" LINE ON THE INSIDE OF THE BODY IS EVEN WITH THE BOTTOM OF THE BOARD. SLIDE THE SQUARE IN THIS POSITION TO WHERE THE INSIDE OF THE TONGUE LINES UP WITH THE"A" MARK. SCRIBE A LINE (DIAGONAL) APPROXIMATELY 2-1/2" LONG ALONG THE INSIDE OF THE TONGUE AT THE BOTTOM OF THE BOARD. THEN SLIDE THE SQUARE TO THE "B" LINE AND SCRIBE A LINE ALONG THE INSIDE OF THE TONGUE AT THE TOP OF THE BOARD. NEXT SLIDE THE SQUARE TO THE "C" LINE AND SCRIBE A LINE ALONG THE INSIDE OF THE TONGUE AT THE BOTTOM OF THE BOARD. THEN SLIDE THE SQUARE TO THE "D" LINE AND SCRIBE A LINE ALONG THE INSIDE OF THE TONGUE AT THE TOP OF THE BOARD.



3. AFTER ALL FOUR DIAGONAL LINES ARE SCRIBED MEASURE DOWN FROM THE 7-13/16" ("A") MARK 1-3/4" ("E") AND SCRIBE A SMALL REFERENCE MARK. THEN MEASURE DOWN FROM THE 11-13/16"("D") MARK 1-1/2" ("F") AND SCRIBE A SMALL REFERENCE MARK. NEXT MEASURE UP FROM THE BOTTOM OF THE BOARD AT THE 6" DIAGONAL LINE 1-1/2"("G") AND SCRIBE A SMALL REFERENCE MARK. THEN MEASURE UP FROM THE BOTTOM OF THE BOARD AT THE 10" DIAGONAL LINE 1-3/4" ("H") AND SCRIBE A SMALL REFERENCE MARK. SCRIBE LINES BETWEEN THE "E" AND "F" MARKS AND THE "G" AND "H" MARKS . REPEAT LAYOUT ON OPPOSITE SIDE OF POST AND TRANSCRIBE LINES ACROSS THE TOP AND BOTTOM OF THE ANCHOR POST.



	FULL DIMENSION	SURFACED
A	6"	6"
B	7-13/16"	7-7/16"
C	10"	9-1/2"
D	11-13/16"	10-15/16"
E	1-3/4"	1 5/8"
F	1-1/2"	1-7/16"
G	1-1/2"	1-7/16"
H	1-3/4"	1 5/8"

4. REMOVE WOOD IN NOTCHES

Figure 13.9 - Notching Layout Using Framing Square

NOTCHING LAYOUT USING FRAMING SQUARE

CALIFORNIA STATE PARKS

NOT TO SCALE

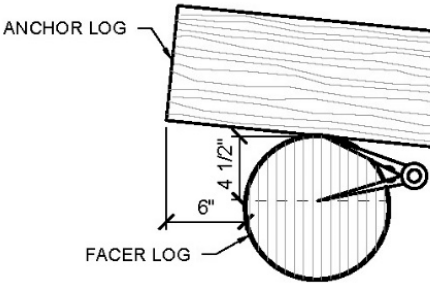
Once all the cuts are performed, the remaining material in the notch is removed using a wood chisel or a beveled broad hatchet. Use a chisel or surform rasp to smooth out the bottom and sides of the notch. This notching technique can also be accomplished with a chainsaw or a circular saw. Chainsaws can also be used to plane off the bottom and sides of the notch. A small chainsaw with a hardened carving bar is particularly effective. If using a circular saw or chainsaw to cut the notches on plastic lumber, it will require frequent cleaning with brake cleaner to remove the build-up of plastic residue.

When the labor force is skilled in using power tools, the assembly of a retaining wall can be performed with greater efficiency. However, if the labor force is unskilled, hand tools should be employed to reduce accidents, improve the quality of the notching, and reduce waste of materials. The efficiency and quality of notching can be increased by obtaining the measurements for the retaining wall and having experienced trail workers fabricate and assemble the retaining wall back at the shop. Mark each piece once the wall is assembled in the shop, and then take it apart for transportation to the worksite, where an unskilled labor force can easily reassemble it. This method is one of the most effective in constructing multi-tier retaining walls.

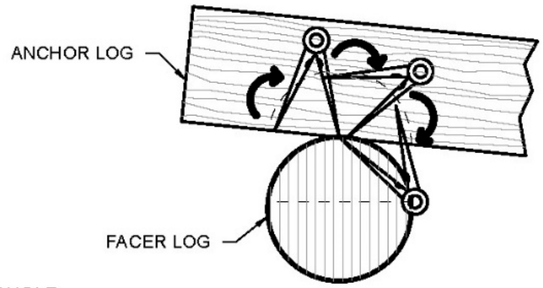
After completing each tier, the area behind the wall is backfilled. Backfill material should be of sufficient size so it will not sift out between the gaps in the wall, and should consist of permeable aggregate, soil, or drain rocks to promote drainage and reduce pore pressure. Rocks larger than 4 inches should not be used as backfill material, because they may leave empty spaces (voids) that could lead to unequal settling.

I. Notching Logs and Split Products

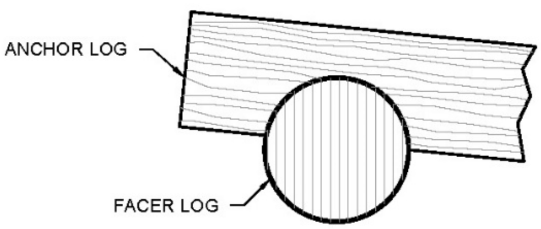
Due to the non-uniform shape of logs and split products, layout and notching requires a custom fit for each structural member. (See Photo 13.5.) The layout for split products is similar to that used with milled lumber, except that the depth of each notch varies as the height and width of the log or split product changes. The same math is applied to determine notching depth but this depth will vary from one member to the next. The layout for logs is similar to the method used in building log cabins, as the material is round and has tapered dimensions. To minimize these variables, select logs or split products that have similar dimensions and lay them on the ground so that they can be compared. Place those closest to the same dimensions adjacent to each other. This simple process also determines the approximate height of the retaining structure once it is assembled. Individual logs or split products can be changed until the desired height is achieved. Alternate logs with distinct tapers, so that the succeeding tier compensates for the taper and the corresponding height differential. (See Figure 13.10.)



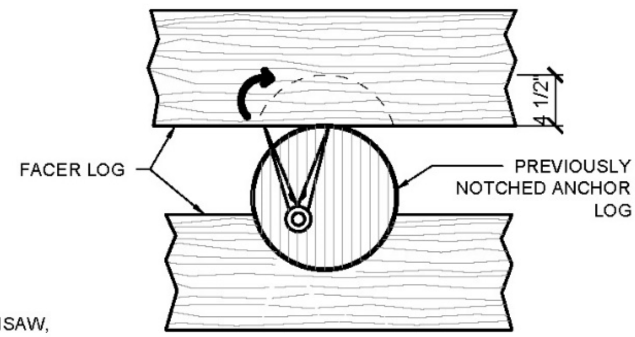
1. PLACE ANCHOR POST ON FACER LOG WITH 10% DOWNWARD ANGLE AND MEASURE DOWN HALF THE DIAMETER OF THE FACER LOG AND SUBTRACT 1/2" (5" - 1/2" = 4 1/2").
2. SET WIDTH OF LOG SCRIBE FROM 4 1/2" INCH LINE AND TOP OF FACER LOG.



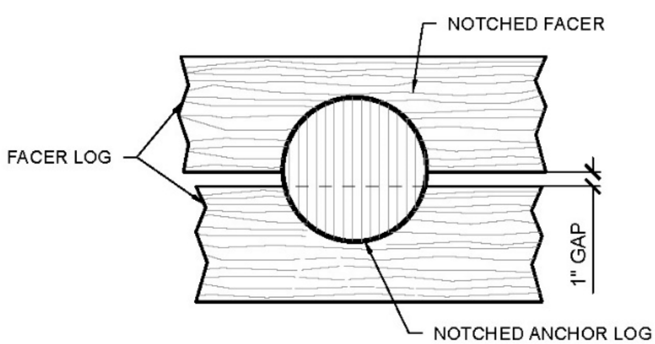
3. SET LOG SCRIBE ON TOP CENTER OF FACER LOG.
4. SCRIBE LINE ON ANCHOR LOG.



5. REMOVE WOOD FROM ANCHOR LOG SCRIBE AREA WITH CHAINSAW, CHISEL & RASP AND SET ANCHOR POST INTO NOTCHES.



6. SET NEXT FACER LOG ON TOP OF ANCHOR LOG.
7. REPEAT NOTCHING LAYOUT & REMOVAL PROCESS ON FACER LOG, NOTCH ON FACER LOG SHOULD BE 1" LOWER (10% OF 10 INCHES) IN BACK TO COMPENSATE FOR THE ANCHOR POST BEING TILTED BACKWARDS 10%



8. REMOVE WOOD FROM FACER SCRIBE AREA WITH CHAINSAW, CHISEL & RASP AND SET FACER ON TOP OF ANCHOR POST.

Figure 13.10 -Notching Details for Interlocking Log Walls

NOTCHING DETAILS FOR INTERLOCKING LOG WALLS CONTINUED

CALIFORNIA STATE PARKS

NOT TO SCALE


Photo 13.5 - Interlocking Log Walls

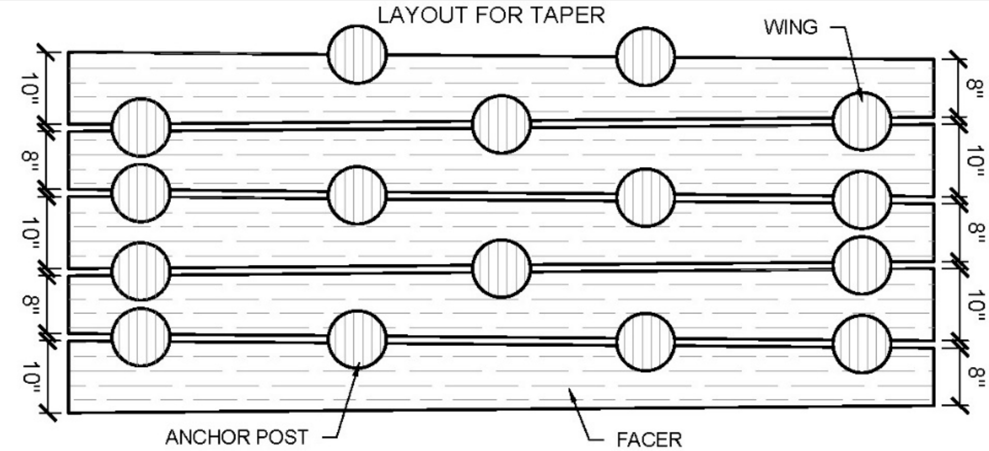
To notch logs so they fit securely, the shapes of each member being joined are scribed on the adjoining member. Use a log-scribing tool to trace the dimensions on the corresponding log. (See Figures 13.10 and 13.11.) Notching is performed with either power or hand tools. Due to the roundness of the logs, the cuts are curved. A small chainsaw with a carving bar works best for these cuts. If hand tools are preferred or are the only option, use a bow saw, coping saw, or key hole saw. The final shaping of the notch is performed with a wood chisel and rasp. To facilitate rolling, moving, and placing logs, use a Peavey. A log dog can be used to keep the logs from moving as they are being scribed and notched. (See Figure 13.12.)

13.9.4.2. Wooden Cribbed Bridge Abutment

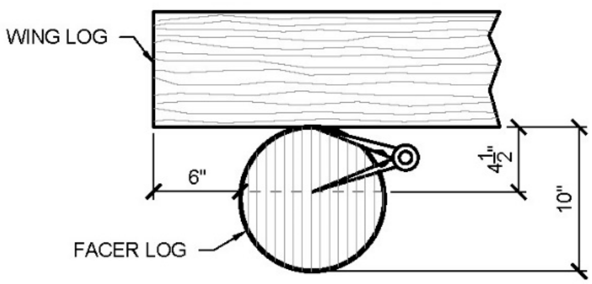
Aggregate-filled wooden cribbing is used for abutments or mid-span supports for trail bridges. (See Photo 13.6.) These structures are constructed almost identically to a multi-tier interlocking retaining wall, except that there are two facer walls and the facers and wing walls are interlocked. Anchor posts are interlocked where they intersect inside the structure, or continued through the structure then notched into the opposing facer or wing wall. (See Figure 13.13.) The purpose of the additional facer wall and interlocking is to unitize the structure so that it can either be free standing or have steps integrated into it. The steps are required to overcome the elevation difference between the approaching trail grade and the top of the bridge. (See Photo 13.7.)

Photo 13.6 - Cribbed Abutment (Using Plastic Lumber)

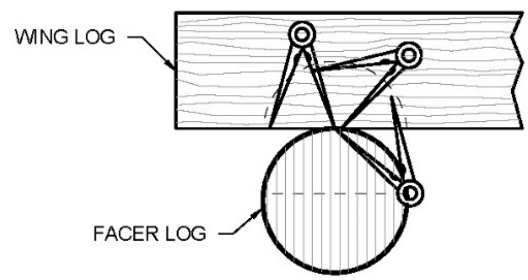
Photo 13.7 – Steps Constructed into a Wooden Cribbed Abutment



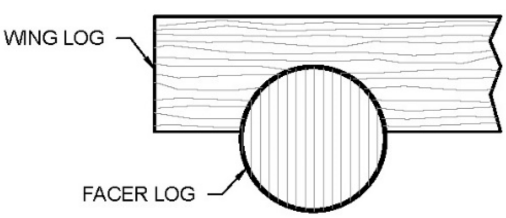
NOTE: NOTCHING IS FOR WING WALLS INSTALLED PERPENDICULAR TO THE FACERS



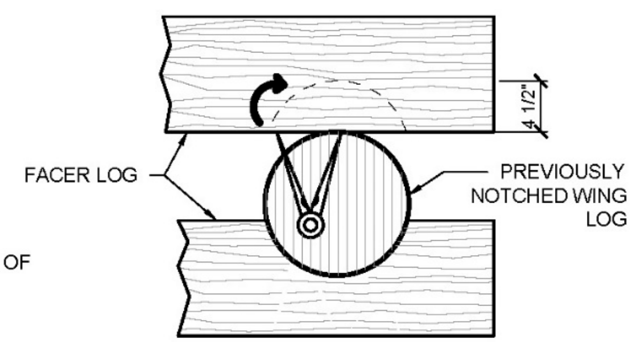
1. PLACE WING LOG ON FACER LOG AND MEASURE DOWN HALF THE DIAMETER OF THE FACER LOG AND SUBTRACT 1/2" (5" - 1/2" = 4 1/2").
2. SET WIDTH OF LOG SCRIBE FROM 4 1/2" INCH LINE AND TOP OF FACER LOG.



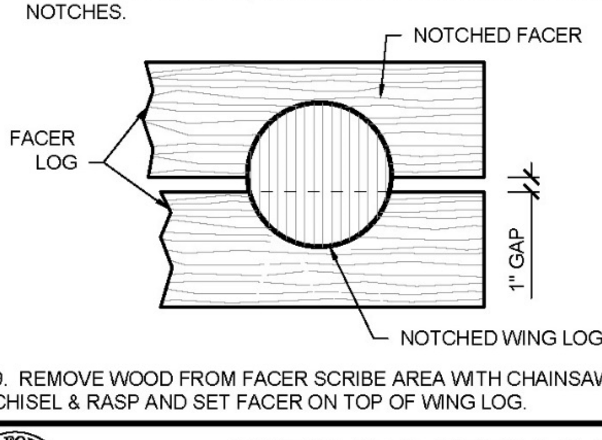
3. SET LOG SCRIBE ON TOP CENTER OF FACER LOG.
4. SCRIBE LINE ON WING LOG.
5. LAYOUT AND SCRIBE OTHER END OF WING LOG.



6. REMOVE WOOD FROM WING SCRIBE AREA ON BOTH ENDS OF WING WITH CHAINSAW, CHISEL & RASP AND SET WING INTO NOTCHES.



7. SET NEXT FACER LOG ON TOP OF ANCHOR LOG.
8. REPEAT NOTCHING LAYOUT & REMOVAL PROCESS ON FACER LOG,



9. REMOVE WOOD FROM FACER SCRIBE AREA WITH CHAINSAW, CHISEL & RASP AND SET FACER ON TOP OF WING LOG.

Figure 13.11 - Notching Details for Interlocking Log Walls Continued

NOTCHING DETAILS FOR INTERLOCKING LOG WALLS

CALIFORNIA STATE PARKS

NOT TO SCALE

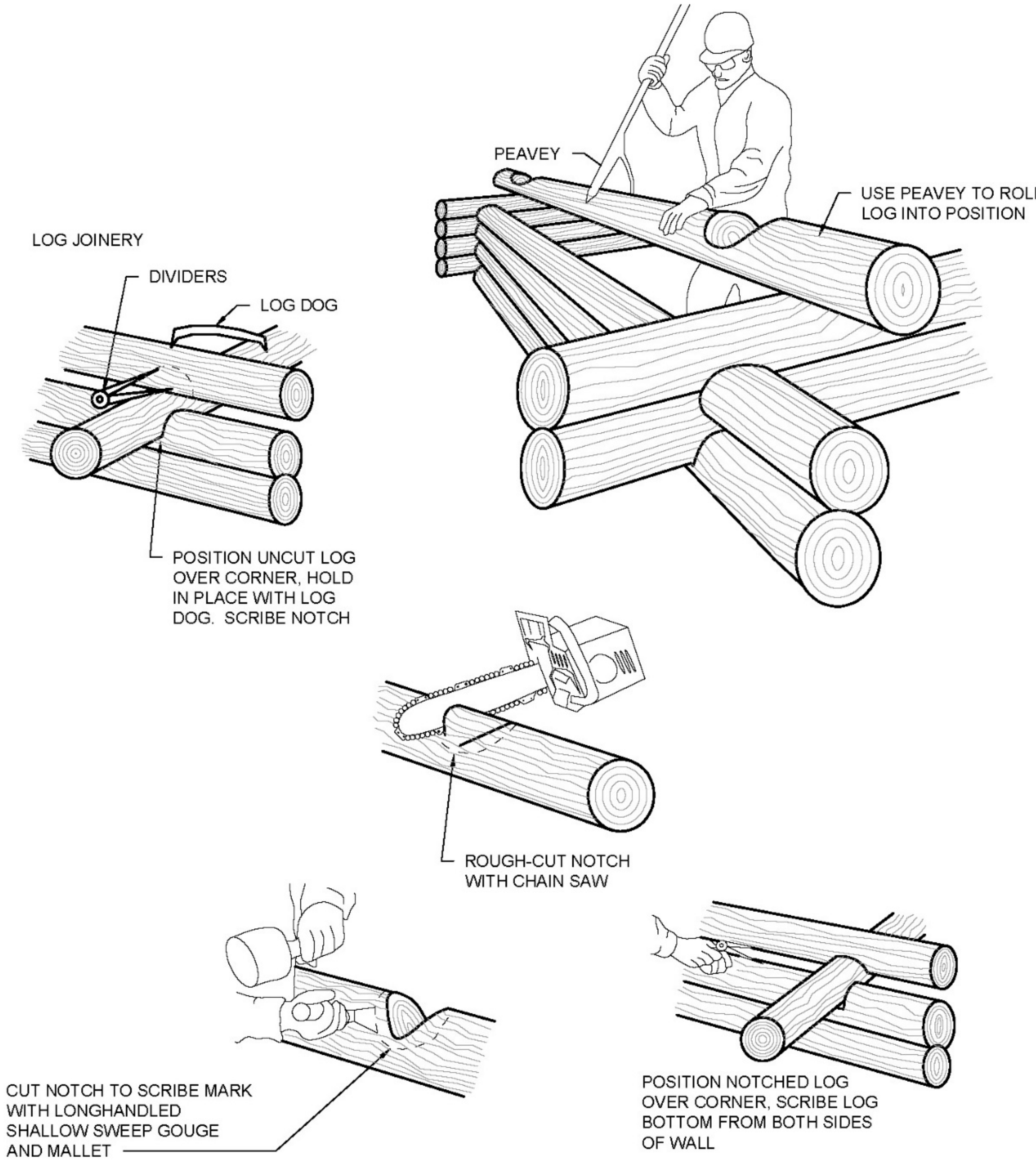


Figure 13.12 - Notching Details for Interlocking Log Walls Continued

NOTCHING DETAILS FOR INTERLOCKING LOG WALLS CONTINUED

CALIFORNIA STATE PARKS

NOT TO SCALE

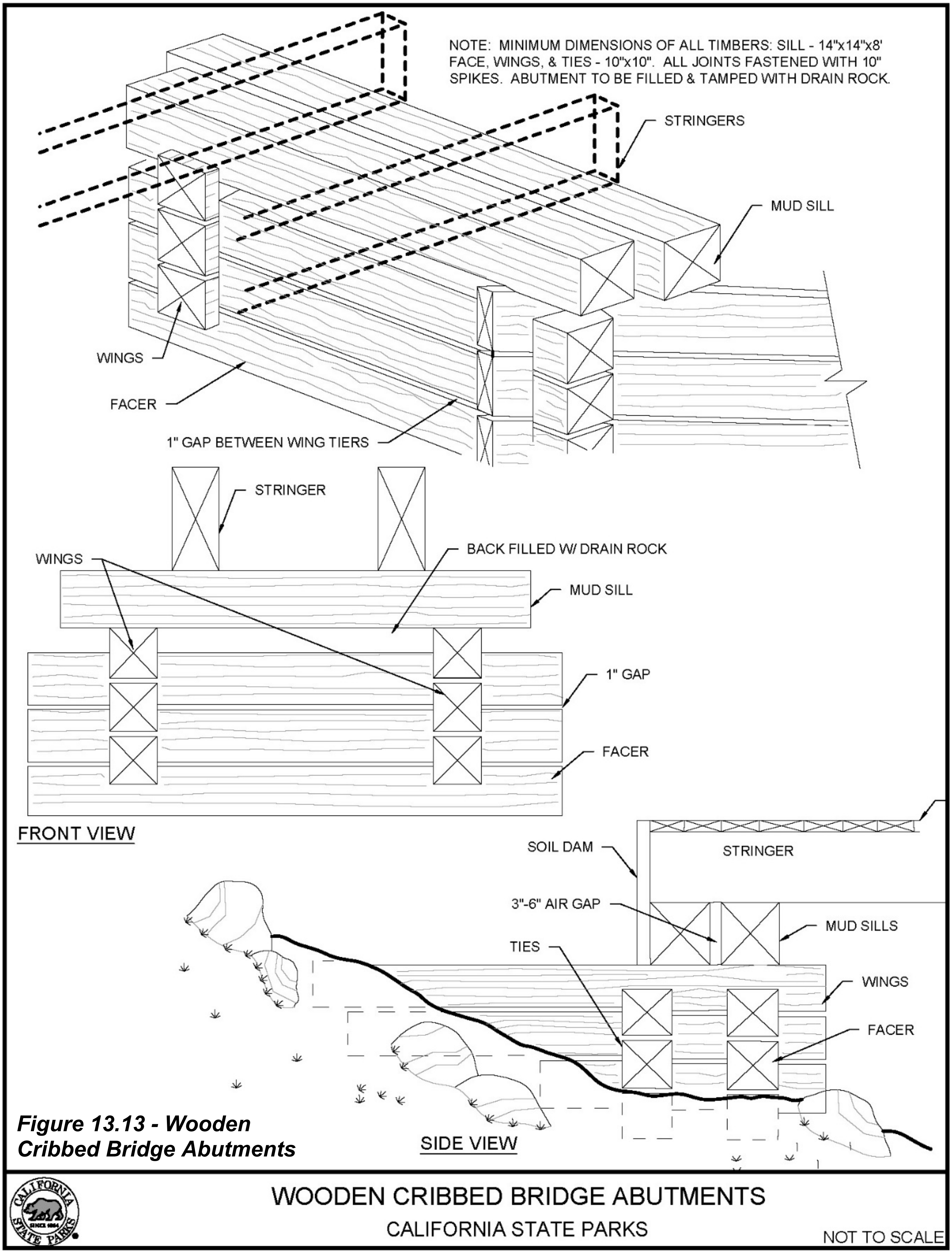


Figure 13.13 - Wooden Cribbed Bridge Abutments

The elevation layout, foundation excavation, and notching are the same as for interlocking wooden retaining walls. However, rather than being constructed into a hill slope, these structures are free standing, built in tiers, and filled with a porous aggregate as each tier is completed.

If constructed within a stream channel (mid-span) or adjacent to a stream channel (abutment), excavation for the foundation follows the same procedure as in the section “Foundation.” The face of the abutment is laid parallel to the stream to minimize deflection of the current toward the opposite bank. The upstream wing wall (shear leg) is laid at an angle of not more than 45 degrees from the line of the stream current, to keep the flow from being directed into the bank. The downstream wing wall (heel leg) is laid at an angle of not more than 60 degrees from the line of the stream flow to reduce the possibility of a back eddy that could erode the bank. (See Figure 13.14.) Wing walls are excavated not less than 48 inches into the stream bank to prevent washing action around the wall end. All abutments should be constructed at an elevation that will ensure the bridge stringers are above future high water events, as described in Chapter 16, *Trail Bridges*. Cribbing is constructed of sound, all-heart redwood, cedar, pressure treated timber, or structural plastic wood.

13.9.4.3. Wooden Cribbed Approach Ramp

A wooden cribbed approach ramp to the end of a bridge is made of wood or plastic wood with a minimum diameter or height of 8 inches. (See Photo 13.8) This type of ramp has the same standards as wooden cribbed abutments and is at least as wide as the bridge deck. The fill grade approaching the bridge should meet or exceed the standards for accessible grades whenever possible. The height of the crib is sufficient to ensure the fill material reaches the level of the bridge deck. (See Figure 13.15.)

Fill material is rock and/or mineral soil, with the final 4 inches of fill consisting of material not larger than 2 inches. All voids should be filled and the material compacted.

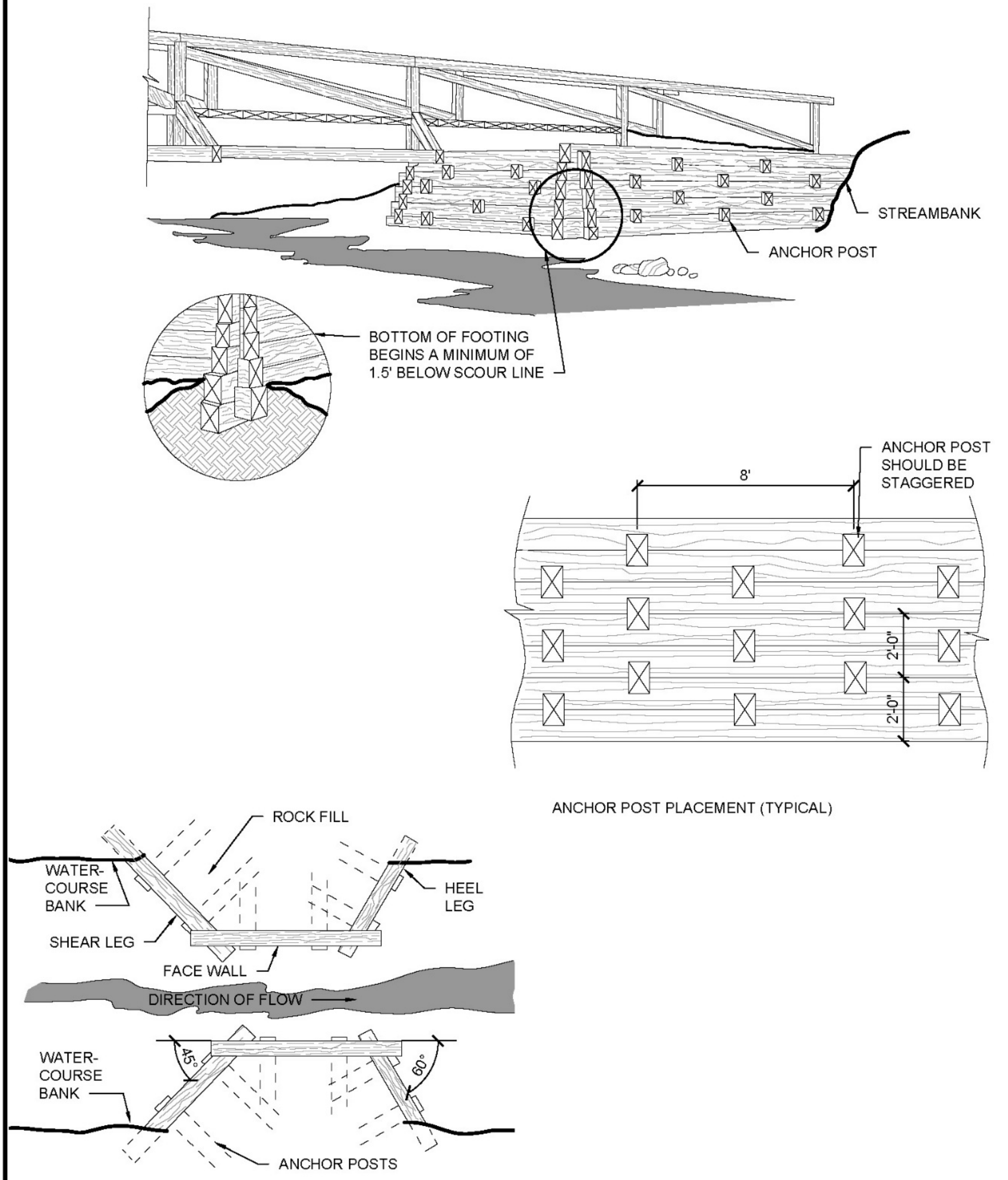


Figure 13.14 - Wooden Cribbed Bridge Abutments Continued

WOODEN CRIBBED BRIDGE ABUTMENTS CONTINUED

CALIFORNIA STATE PARKS

NOT TO SCALE

Photo 13.8 - Wooden Cribbed Approach Ramp

13.10. Multi-Tier Rock Wall Retaining Structures

13.10.1. Applications

Multi-tier rock retaining structures can be used in a variety of designs but require advanced stone masonry skills to construct. (See Photo 13.9.) These structures are effective at stabilizing the trail bed and retaining fill material below the trail, stabilizing back slopes, and retaining fill used to bridge over tree roots and rocks. They are also used as abutments, mid-span supports, and ramps for bridges. These structures are constructed in tiers using gravity and friction (dry stone masonry) or gravity, friction, and mortar (wet masonry).

13.10.2. Attributes

Multi-tiered rock retaining structures are very effective at retaining and containing fill. They can be used for almost any type of retaining structure application and have the structural capacity to retain moderate amounts of fill. If on-site native materials are generated during the clearing and construction of the project, or are gathered or quarried close to the worksite, the building materials for these structures are inexpensive and blend in with the environment. Properly constructed rock retaining structures have the longest life span of any retaining structure. Dry stack rock retaining walls last hundreds of years. Many rock structures constructed by ancient cultures over a thousand years ago are still functional today. Wet masonry walls have a shorter life span, as they deteriorate once the mortar begins to fail, but their life span is significantly longer than that of other retaining structures.

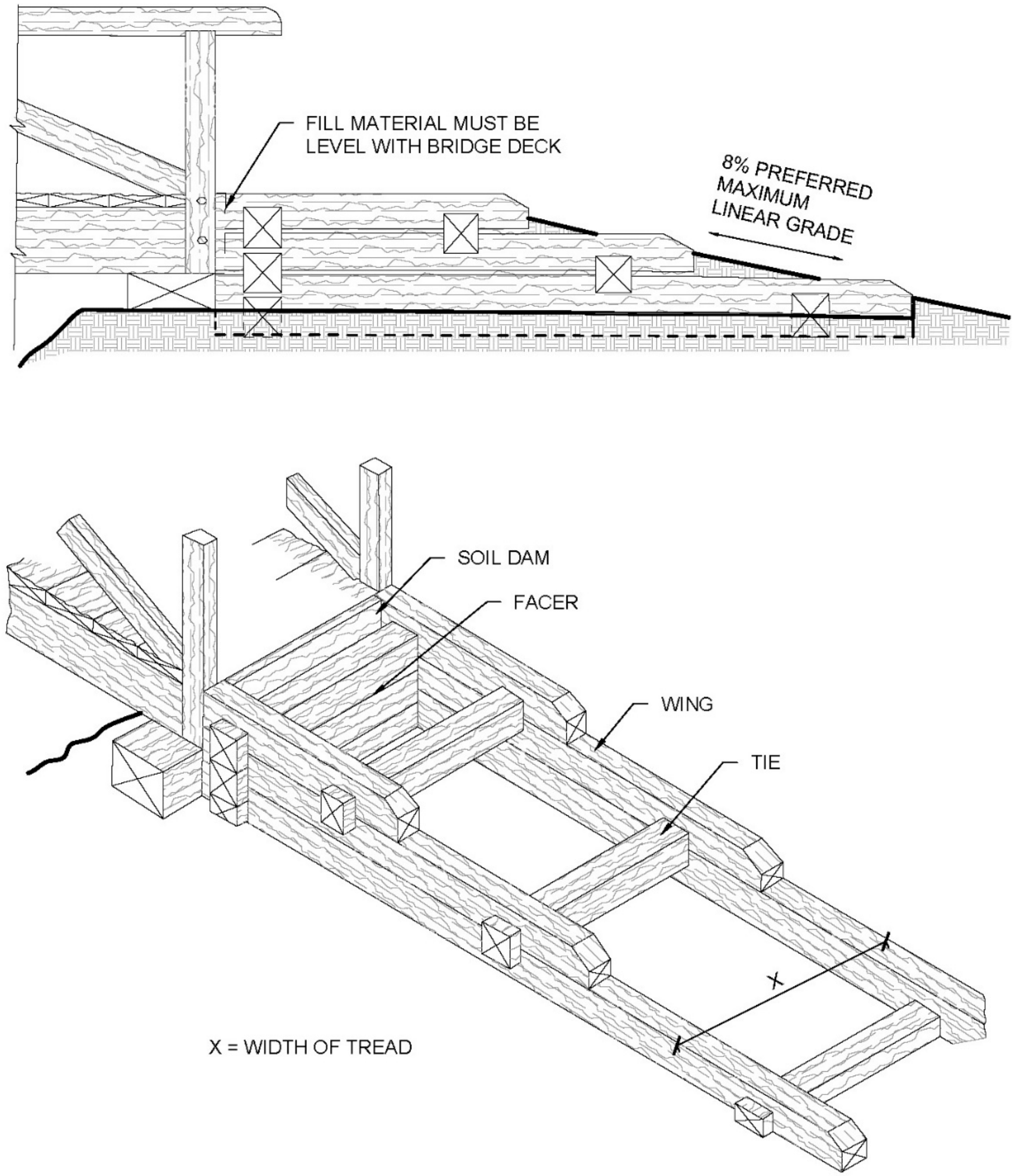


Figure 13.15 - Wooden Cribbed Approach Ramps

WOODEN CRIBBED APPROACH RAMPS

CALIFORNIA STATE PARKS

NOT TO SCALE

Photo 13.9 - Multi-Tier Rock Retaining Wall

13.10.3. Limitations

Multi-tiered rock retaining structures must be built by trail workers skilled in rock masonry. The logistics of transporting and placing rock can be time consuming and hazardous. Finding suitable rock close to the project worksite may be a limiting factor. It may be difficult to transport rock from a commercial quarry to the trail, or it may be difficult to locate rock that has the same color and texture as the native rock. Travel distance, access to water (for wet masonry), and transportation from the trailhead to the worksite can make importing rock cost-prohibitive.

13.10.4. Logistics

Usually the rock is generated from trail clearing and excavation, or is gathered from outcroppings or talus slopes close to the worksite. Rock can also be imported to the worksite when transportation costs are favorable or architectural or design requirements call for the use of rock.

Rock is gathered or quarried to the desired shape and size through the use of rock drills, explosives, expansion agents, or wedges and shims. Quarrying rock is labor intensive and requires skilled trail workers. Unless there is easy access to a good rock source and skilled workers, this option quickly becomes cost prohibitive. Quarrying, gathering, transporting, and placing rock must be approached in the most efficient manner possible. Prior to quarrying or gathering rock, the volume of rock needed for the structure must be determined. This volume must include both wall rock and crushed fill. The desired size and shape of the rock must also be identified. The rock source is often limited, but when options are available, only the preferred rock should be gathered or generated. Rocks for the retaining wall must be solid.

Those selected for crushed fill can be less competent (more fractured) since they will be broken into smaller sizes and fractured rock is easier to crush. The size and weight of the rock may also be limited by the method of transportation, distance to the worksite, and ability of the trail crew to place the rock efficiently and safely when building the wall. A trail supervisor or someone with advanced rock wall construction skills should identify suitable rock by chalk marking selected rocks with an “X” and segregating them by size (or thickness). This method should prevent unsuitable rock from being transported to the site, often at considerable time and cost. Segregating the rock by shape and thickness also allows trail workers to efficiently access the necessary rocks during construction.

Place the rock at the worksite (segregated by thickness) above the intended wall and out of the construction area to allow trail workers to move the rocks downhill when they need them. Also, the wall rocks should be spread on the ground where they can be easily viewed, rather than stacked in a pile to eliminate having to rummage through a pile every time a rock is needed. Rock for crushed material can be piled above the worksite, as this rock will be broken into smaller pieces and placed behind the wall rock. If the project is large and many rocks are needed, the work area may become too congested and unsafe. Gather only the number of rocks the stockpile area will comfortably hold, yet still provide an adequate selection.

Imported rock usually comes from a commercial quarry. When purchasing rock from a quarry, specify that the rock will be hand-selected by the trail crew. The crew will require access to the quarry to choose the rocks that best meet the project requirements and produce the most competent and efficient wall. Selected rocks are marked with chalk (by the trail supervisor) and placed in a pile where they can be loaded by the quarry operator and trucked to the trailhead. If pre-selection is not performed, then most likely the rocks that are received will be of unsuitable sizes and shapes and difficult or impossible to use in construction.

The trail crew may be required to complete a quarry safety training course prior to being allowed to enter the quarry. However, this small investment in training will pay off in project efficiency when only suitable rocks are purchased, transported to the project site, and used to construct the retaining wall. If a quarry will not allow a crew to enter, the trail supervisor can sometimes arrange to work with one of the quarry’s heavy equipment operators to help select the desired rocks. The trail supervisor selects and marks the rocks and the operator uses an excavator with a thumb to pull out the desired rocks. They are then loaded and trucked to the trailhead. If the rock cannot be pre-selected at the quarry, then have the rock delivered to a corporate yard where the trail crew can select the desired rocks for transport to the trailhead. In this case, purchase more rock than needed so there is sufficient material from which to select. The amount of extra rock that should be purchased will depend on the quality of the rock in general. The remaining rocks can be used where good rock shapes are not required, such as non-structural (“junk”) walls, slope protection, energy dissipation, or road backfill projects.

Transporting rocks often represents the most time consuming and dangerous components of a rock retaining wall project. For short distances, rock can be carried in a rock stretcher or litter. Rock also can be transported along a skyline (up to several thousand feet if sight lines, anchors, rigging equipment, and expertise are available). It can be hauled in wheelbarrows for several miles if the trail tread and linear grades are suitable and the labor force sufficient to shuttle the wheelbarrows. Rock can also be transported by pack stock several miles, if the rocks are not too large. Finally, rock can be transported several miles using motorized toters on trails with the appropriate width and linear grades and no obstructions.

The methods described above can also be used to move native rock overland or down the trail when it is in close proximity to the worksite. However, wheelbarrows and motorized toters have limited off-trail capabilities. In addition to these methods, a trail worker can roll a rock using their hands, arms, and legs for levers (sometimes referred to as "piss-anting") or by using a rock bar. This method is somewhat limited to short distances across flat or moderately sloped ground. When the slope becomes too steep, it becomes dangerous to move the rock downhill. Controlling the descent of the rock with a worker downhill of the rock is dangerous, even when a shovel or rock bar is used to retard movement of the rock. Moving rock uphill places the worker in a similarly compromised position, and also requires overcoming greater gravitational force. Using pack stock to drag a sled or a stone boat is effective for moving rock across flat or moderately sloped ground. The limiting factors of any method are distance and terrain.

Placing rock on the wall is challenging when working with large rocks on varied terrain or in a tight workspace. Rocks can be rolled, carried by one or more workers or a rock stretcher, or transported by a skyline and lowered onto the wall. The method selected should provide the greatest worker safety, resource protection, operational efficiency, and precision.

13.10.5. Construction

Multi-tier rock retaining walls can be constructed without mortar (dry stone masonry) or with mortar (wet masonry). Most of the techniques to build these two types of walls are identical. For simplification, the dry stone technique will be addressed first since it is the most common in trail construction. Then the differences in wet stone masonry will be addressed.

13.11. Dry Stone Multi-Tier Rock Retaining Walls

13.11.1. Layout and Foundation

Planning a rock retaining wall requires taking into account the natural features of the site. Well-anchored rocks and bedrock already in place can be used as keystones, which improve the wall's structural stability. Multi-tier rock retaining walls begin with excavation of a foundation as described in the section "Foundation and Wall Batter." The location of the foundation is laid out so that the wall begins below the trail and far enough away from the outboard hinge of the trail so that when the wall is finished the top of the wall is below the outboard hinge of the trail. The layout should account for the overall height of the wall and the batter being applied. The elevation of the bottom of the foundation must also be determined, so it is located on stable ground, and the combined height of the tiers in the wall is slightly below the finished height of the outboard hinge of the trail. (See Figure 13.16.)

When natural features such as large rocks and bedrock are incorporated into the foundation, or when the native ground has varying elevations, it is often necessary to construct multiple foundations. (See Photo 13.10.) These foundations can be located at opposite sides of bedrock that protrudes into the wall location, or at different elevations to compensate for differences in ground height along the length of the wall. (See Photo 13.11 and Figure 13.17.) Starting foundations at different elevations may be necessary to keep each wall course level. Rock walls constructed within these foundations will join together by overlapping the higher wall over the lower wall. The builder must account for differences in elevation by adjusting the depth of the foundations, the height or thickness of the rock selected, and the number of tiers constructed. By planning for varying elevations in advance of construction, the trail crew can select rocks that facilitate the leveling and joining of two wall sections. When two walls come together from perpendicular or nearly perpendicular angles, they are joined with overlapping joints. These joints are alternated so there is not one, continuous seam. (See Figure 13.18.) Overlapping joints are common when multi-tier rock walls are used for abutments or mid-span support structures.

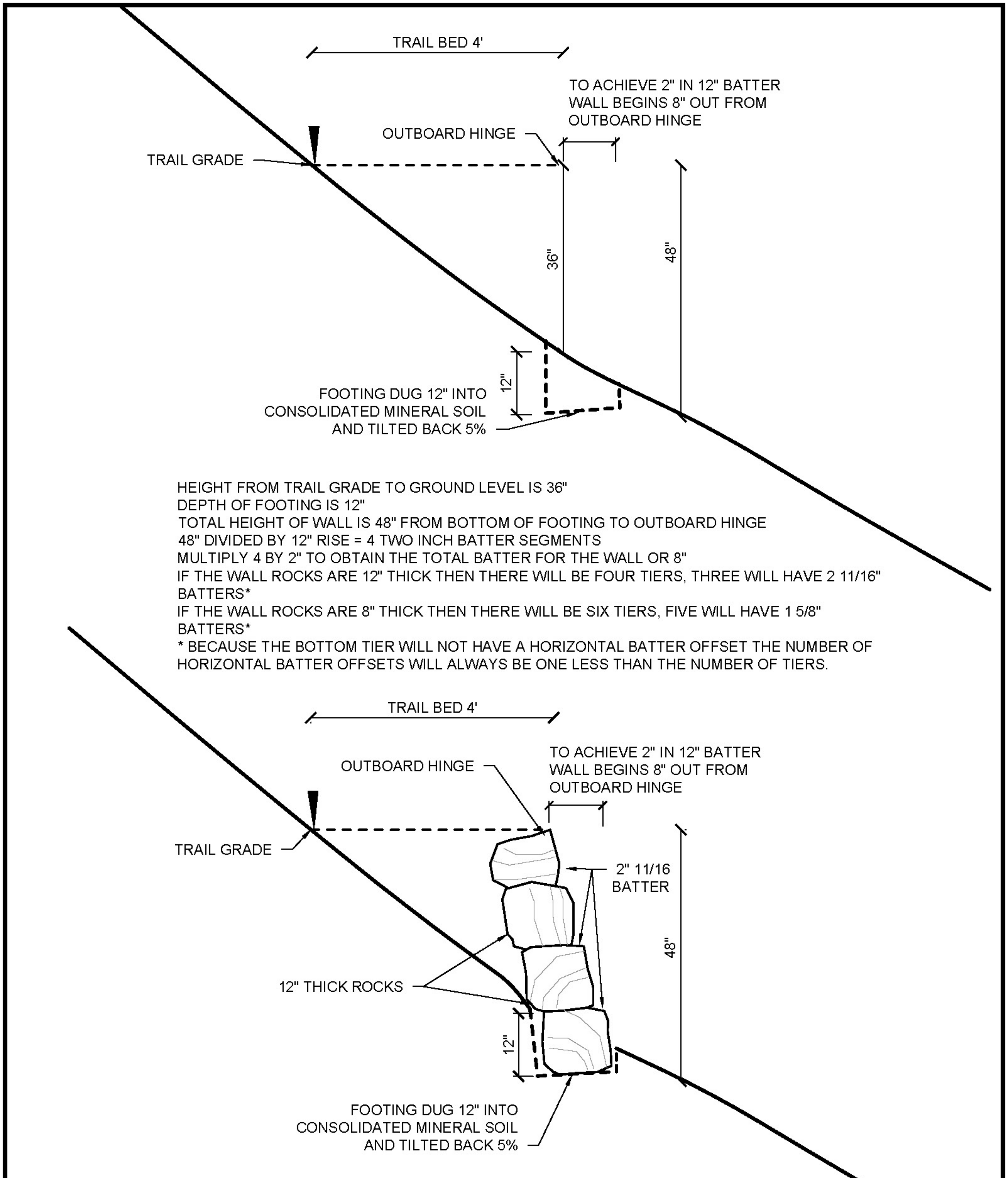


Figure 13.16 – Multi-tier Rock Retaining Walls Layout

MULTITIER ROCK RETAINING WALLS LAYOUT

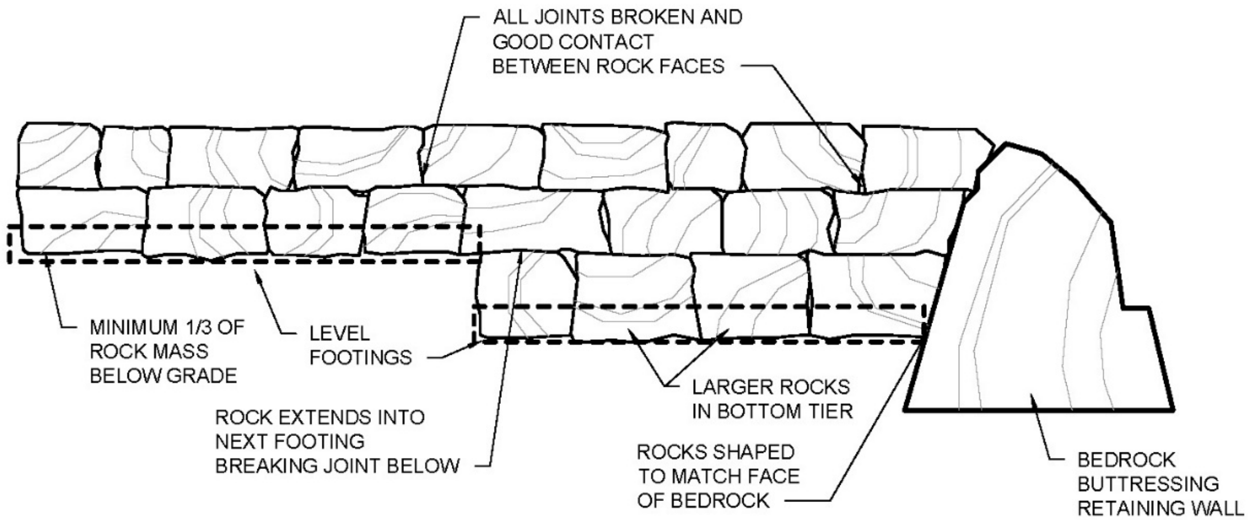
CALIFORNIA STATE PARKS

NOT TO SCALE

Photo 13.10 - Foundations at Different Elevations

Photo 13.11 - Rock Wall Bedrock Buttress

MULTITIER ROCK WALL WITH BEDROCK BUTTRESS AND MULTI LEVEL FOOTINGS



MULTITIER ROCK WALL BUTTRESSED BETWEEN TWO BEDROCK OUTCROPS WITH MULTI LEVEL FOOTINGS

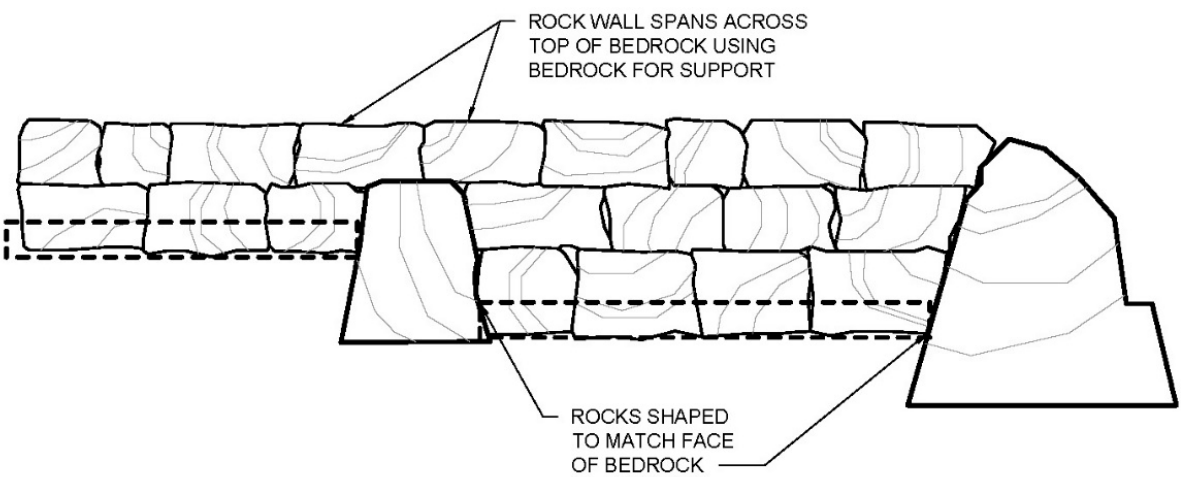


Figure 13.17 – Multi-tier Rock Retaining Wall with Bedrock Buttress

MULTITIER ROCK RETAINING WALL WITH BEDROCK BUTTRESS

CALIFORNIA STATE PARKS

NOT TO SCALE

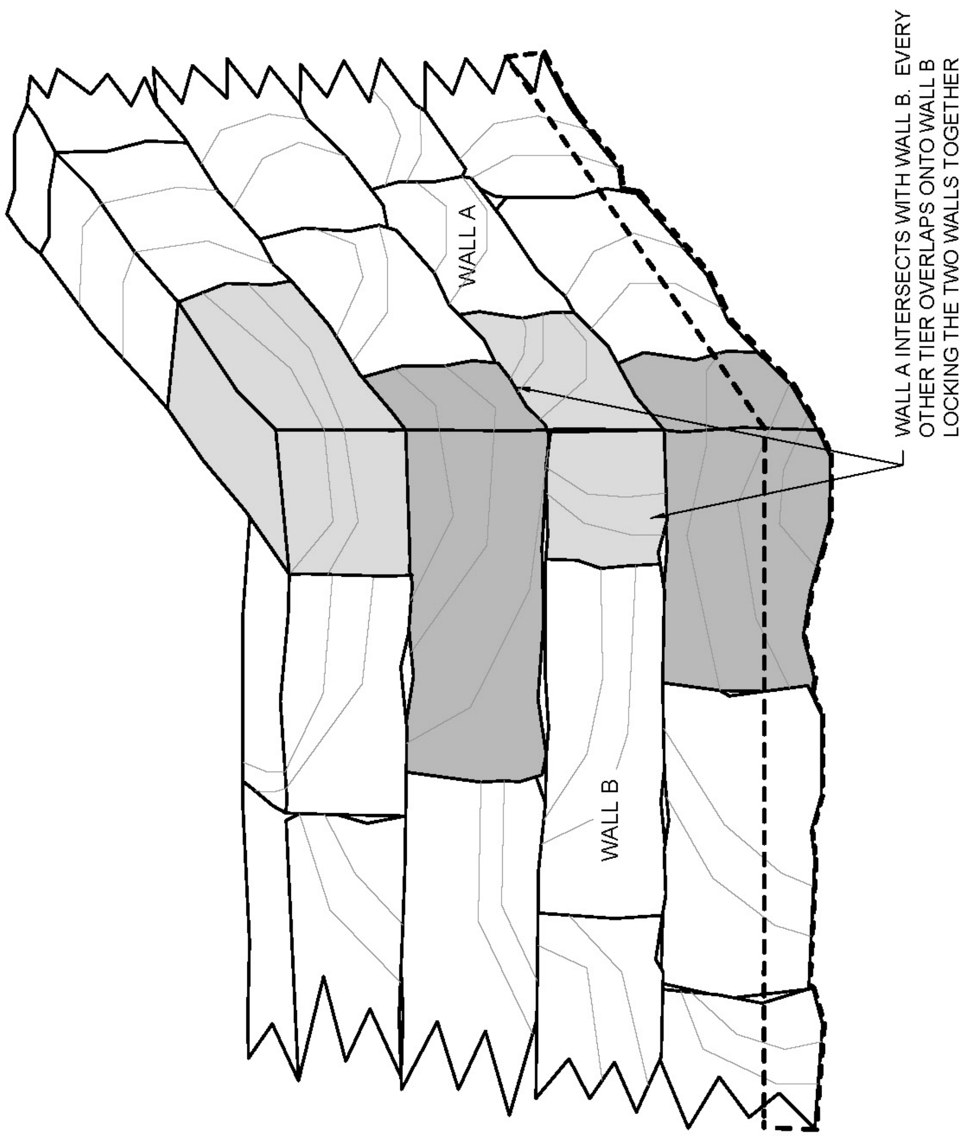


Figure 13.18 – Multi-tier Rock Retaining Wall Overlapping Joints

MULTITIER ROCK RETAINING WALL OVERLAPPING JOINTS

CALIFORNIA STATE PARKS

NOT TO SCALE

13.11.2. Construction

Construction begins after the site plan is developed, the foundation excavated, and the rocks delivered to the site. The foundation is excavated so that it is level. However, protruding bedrock or large boulders can cause the foundation to slant to one side. In this case, start the wall at the lowest end of the footing. The first rock laid should be a substantial size, as it will become the keystone that buttresses the rest of the wall. Typically, this rock is the largest in the retaining wall. (See Figure 13.19.) Because the top of the wall is slanted, it is often necessary to pin the second rock onto the first (bottom) and to continue pinning seceding tiers to keep the rocks anchored to the rocks beneath them and prevent them from sliding downhill. The pinning is achieved by drilling a 7/8-inch hole through the second tier rock and halfway into the first tier rock. Once the hole is cleaned out, a 3/4-inch diameter stainless steel rod is inserted into the hole and glued in place with two part epoxy glue. (See Figure 13.19.) When installing pins, it is important that the top of the hole is completely sealed with epoxy glue to keep water out of the hole, which can lead to fracturing in below freezing conditions. If aesthetics are a concern, a portable rock coring machine can be used to core out the top of the pin hole. After the pin is driven below grade into the hole, the rock core is glued into the top of the hole, hiding the hole and pin.

The first tier of rock needs three good surfaces for making contact: the ends for contact with the rocks next to it, and the top for contact with the next tier. The bottom of the rocks can be of irregular shape, as they are buried at the bottom of the footing. The footing can be dug out to conform to the shape of the rock. Adjusting the bottom of the footing to conform to the bottom of the rock allows the builder to use rocks of different thickness or with uneven surfaces on the bottom tier. Save the rocks with a flat top and bottom for the next tiers. It is also important to use large rocks in the bottom to give the wall greater stability by keeping its overall mass low in the structure. This placement also allows the rock to be laid with the bulk of its weight set back into the wall. Foundation rocks are laid so that they do not overhang or protrude beyond the front of the footing. Set foundation rocks so they are firm and stable and have good contact with the wall rock next to them. Full contact along the face of adjoining rocks is preferable. If full contact is not possible, there should at least be solid contact between the upper portions (high contacts) of the two rocks. (See Figures 13.19 and 13.20.)

A rock bar is an essential tool for levering two rocks together, especially foundation rock, as the soil they are set on inhibits sliding them together. One or two rock bars used properly facilitate a tight joining of the two rocks. The top of the foundation tier must be flat to provide good contact and a solid base for the next tier of rock. Some shaping of the rocks may be necessary to ensure good contact. Use hand tracers or slab/rifting hammers to split or break the rock, hand chisels to break off or shape protruding points, hand points to remove high spots on the rock, or handsets to remove small ledges or drill marks. Double Jacks (sledge hammers), single jacks (hand sledges), spalling hammers, and mash hammers may also be needed to strike these tools or break and crush rock. (See Photo 13.12.)

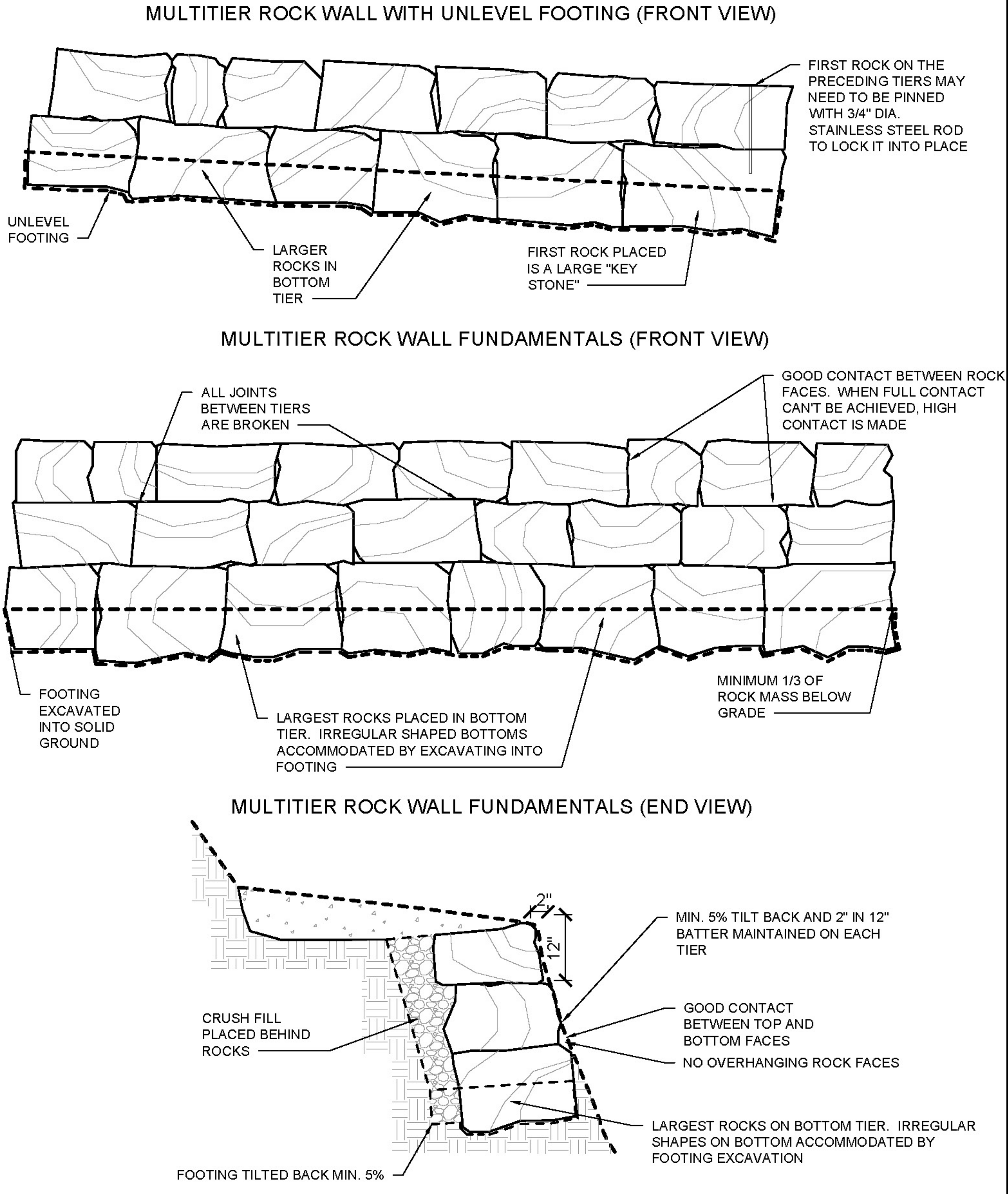


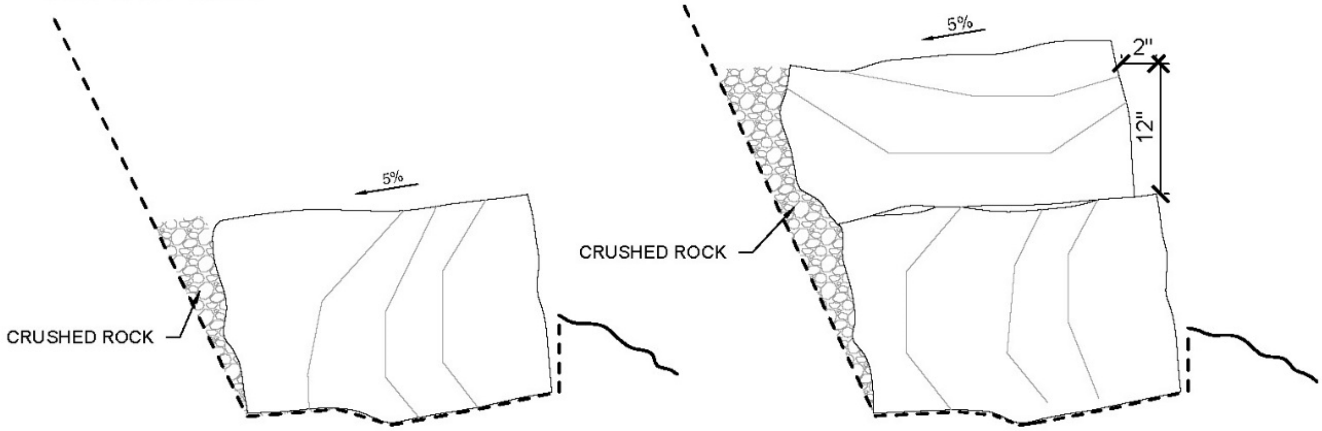
Figure 13.19 – Multi-tier Rock Retaining Wall Fundamentals

MULTITIER ROCK RETAINING WALL FUNDAMENTALS

CALIFORNIA STATE PARKS

NOT TO SCALE

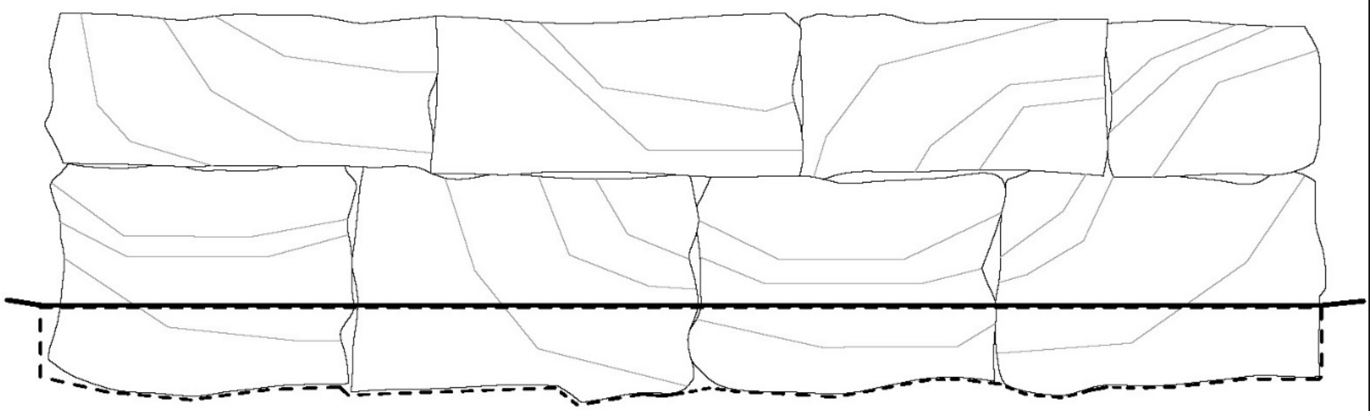
SECTION VIEW



1. FOUNDATION IS EXCAVATED INTO STABLE/NATIVE MINERAL SOIL WITH A MINIMUM 5% TILT INTO THE HILLSLOPE.
2. THE BOTTOM TIER IS COMPRISED OF THE LARGEST STONES AND A MINIMUM OF 1/3 OF THE STONES' MASS ARE BELOW GRADE.
3. THE BOTTOMS OF THE STONES CAN BE IRREGULARLY SHAPED AS THEY ARE ACCOMMODATED BY EXCAVATING INTO THE SOIL FOUNDATION.
4. THE TOPS OF THE BOTTOM TIER STONES ARE RELATIVELY FLAT TO PROVIDE GOOD CONTACT WITH THE NEXT TIER OF STONES.
5. THE TOP OF THE BOTTOM TIER MAINTAINS THE MINIMUM 5% TILT BACK.
6. THE VOIDS BEHIND THE STONES ARE FILLED WITH CRUSHED ROCK.

1. THE SECOND TIER STONES ARE LAID WITH A MINIMUM 2" IN 12" BATTER.
2. THERE IS GOOD CONTACT BETWEEN THE TOPS OF THE FIRST TIER STONES AND THE BOTTOMS OF THE SECOND TIER STONES.
3. THE FACES OF THE SECOND TIER STONES DO NOT PROJECT OUT BEYOND THE FIRST TIER.
4. THE TOPS OF THE BOTTOM TIER STONES ARE RELATIVELY FLAT TO PROVIDE GOOD CONTACT WITH THE NEXT TIER OF STONES.
5. THE TOP OF THE SECOND TIER MAINTAINS THE MINIMUM 5% TILT BACK.

FRONT VIEW



1. THE LARGEST STONES ARE IN THE BOTTOM TIER AND EACH SUCCESSIVE TIER OF STONES IS NEVER LARGER THAN THE PRECEDING TIER.
2. THE TOPS AND SIDES OF THE STONES HAVE GOOD FACES WHICH PROVIDE GOOD CONTACT BETWEEN ADJOINING STONES.
3. GOOD CONTACT IS MADE BETWEEN THE SIDES OF THE STONES AND HIGH CONTACT BETTER THAN LOW CONTACT.
4. ALL JOINTS ARE BROKEN (STAGGERED) AND GOOD CONTACT IS MADE ON EACH SIDE OF THE JOINT.
5. EACH TIER OF STONES IS RELATIVELY LEVEL MAINTAINING AN EVEN DISTRIBUTION OF WEIGHT ALONG THE WALL.

Figure 13.20 - Rock Laying Fundamentals

ROCK LAYING FUNDAMENTALS

CALIFORNIA STATE PARKS

NOT TO SCALE

Photo 13.12 - Rock Working Tools

Shaping rock with these tools expedites the joining of the rocks and improves contact between them. However, shaping is labor intensive, so it is important to select rocks that will work together and that require the least amount of shaping. Follow the process below to select the best rocks.

When selecting rocks for a retaining wall it is advisable to use a tape measure to identify the size, shape, and thickness of the rock needed. Then go to the pre-sorted rocks stored above the worksite and find those rocks that meet the necessary dimensions. Too often rocks that cannot be used are carried to the wall. Moving unusable rocks to the wall or having unusable rocks in the way of construction is inefficient. It is also advisable to select several rocks at a time that have approximately the same size and appear to fit together. Sometimes these rocks can be quickly fitted together where they are stored to see their potential for use in the wall. Move the rocks around and turn them over to see which combination works best. This visual test allows several rocks to be moved to the wall at the same time with a high probability that they will work together in the wall. The process of selecting one rock at a time, shaping it to fit, and then finding another rock to match that rock can often be a very frustrating and inefficient process.

All wall rocks should be laid with their greatest dimension extending into the wall. At least one-quarter of the rocks should be “header rocks” or rocks that extend a minimum of two feet into the backfill behind the wall. These rocks perform a similar function as anchor posts.

Once the initial foundation is complete, the back of the wall is filled with crushed rock. This rock is broken or crushed with a double jack at a distance from the wall, so that the breaking of the rock does not disturb or damage the rocks just fitted in the wall. Once broken into sufficiently small sizes (2 to 4 inches in diameter), the crushed rock is carried to the wall in a rock litter or bucket, placed behind the wall rock, and then further crushed with a single jack, spalling hammer, or mash hammer. The smaller fractured rock is then stuffed behind the wall rock in a fashion that does not move or disturb the wall rocks or compromise their points of contact, so that all voids are filled with crushed angular rock and the backs of the wall rocks are fully supported. Once the backs of the wall rocks are stuffed and supported, the remainder of the footing behind the wall is filled with crushed rock to the same elevation as the wall rocks. Test the wall rocks for stability by walking along the outer (front) edge of the rocks and checking for movement or rocking. When a worker's full weight is placed on the outer edge, the rocks should not move or tilt. If movement occurs, the cause must be identified and corrected prior to proceeding to the next tier.

Once the initial foundation is complete and the back of the wall is filled with crushed rock, construction of the second tier can begin. For long walls, it may not be necessary to wait until the bottom tier is finished to start the second tier. After enough rocks have been laid and backfilled with crushed rock to provide a safe working space between the two courses, workers can proceed to the second tier. Construction must be monitored carefully to ensure that the wall is conforming to the intended design and is structurally sound. As mentioned in the section on "Foundation and Wall Batter," multi-tiered walls over 3 feet high require a minimum batter of 2 inches in 12 inches. The required batter should be accounted for in the initial foundation layout. Rocks placed on top of the first tier need to reflect the prescribed batter. Use a string line to guide the starting point or front of the wall for the second tier. Attaching a line level to the string also allows the builder to monitor how level the top of the wall is.

Installing the second tier is similar to installing the foundation except that there must be solid contact between the top of the foundation rocks and the bottom of the second tier rocks. To ensure wall stability, each rock placed in the upper tier should have a minimum of three contact points with the lower tier. Therefore, carefully select and/or shape rocks as appropriate. The rocks in the second tier must span the joints between rocks in the foundation tier. (See Figure 13.20.) The second tier must also maintain the minimum 5% rearward tilt that transfers the weight off the wall and into the hill slope. To achieve this tilt requires selecting rocks that have the appropriate taper. The higher end of the taper should always be on the face of the wall.

Once the second tier is complete, the back of the wall is carefully chinked (hand pressure only) and voids are filled with appropriately sized crushed rock ("stuffed"). When the backs of the wall rocks are stuffed and supported, the remainder of the footing behind the wall is filled with crushed rock to the same elevation as the second tier wall rocks. Subsequent tiers are constructed in a similar fashion until the designed height is achieved. The top of the retaining wall affects the trail bed drainage design. If the trail bed is outsloped, the top of the wall must be lower in elevation than the outboard hinge of the trail tread. Once the wall is complete, the front of the wall can be chinked by placing rock wedges into the gaps left between rocks to add stability. Chinking is performed only after the wall is complete, because without the full weight of the wall, placing rock wedges into the gaps can wedge the wall apart, eliminate points of contact, and destabilize the wall. Chinking is not intended to fill every gap in the face of the retaining wall; only the largest ones. Gaps are necessary to provide drainage from the back of the wall and to relieve pore pressure.

Fill material should be rock and/or mineral soil, with the final 4 inches consisting of material not larger than 2 inches. All voids should be filled and the material compacted.

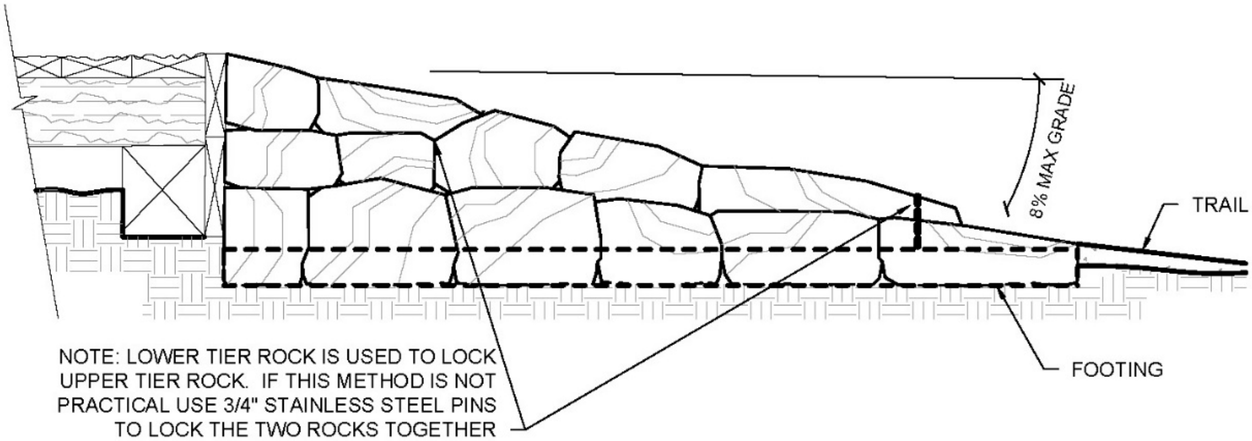
13.12. Multi-Tier Rock Approach Ramps

Multi-tier approach ramps to a bridge have the same design and construction standards as multi-tier rock retaining walls and the ramps are at least as wide as the bridge deck. (See Photo 13.13.) The finished grade of the fill approaching the bridge should meet or exceed the standards for accessible grade whenever possible. The height of the ramp wall is sufficient to ensure the fill material rises to the level of the bridge deck. (See Figure 13.21.)

Photo 13.13 - Multi-Tier Rock Approach Ramp

13.13. Wet Masonry Multi-Tier Retaining Walls

The same tools, materials, and equipment required to construct dry stone masonry walls are needed for wet masonry walls. (See Photo 13.14.) In addition, wire brushes, water, concrete, mortar, mortarboards, mixing hoes, trowels, pointers/jointers, and sponges are also necessary for wet masonry. These additional tools, along with project logistics and aesthetics, usually limit wet masonry walls to use on Class I trails.



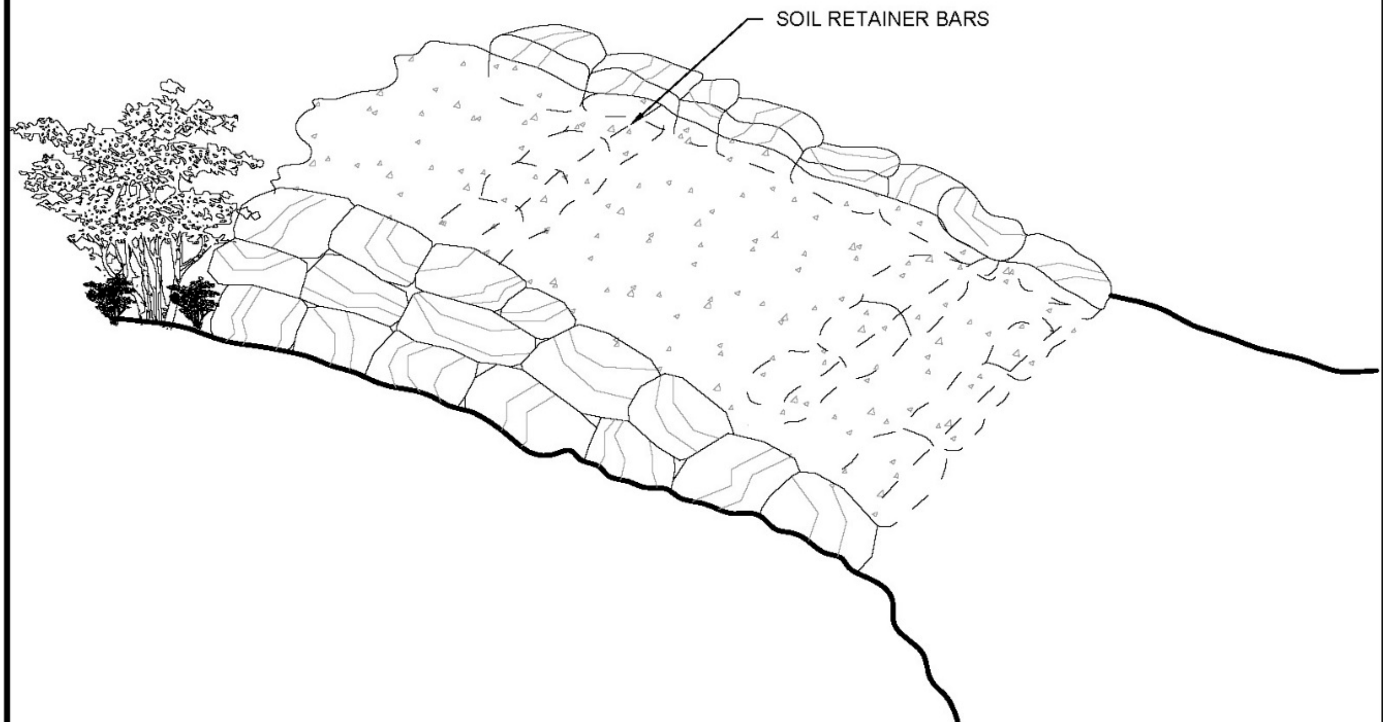


Figure 13.21 - Rock Approach Ramp

ROCK APPROACH RAMP

CALIFORNIA STATE PARKS

NOT TO SCALE

Photo 13.14 - Wet Masonry Wall

13.13.1. <u>Layout and Construction</u>

The layout and construction of the foundation is identical to that of dry stone masonry walls. However, the initial foundation is laid on top of a wet layer of concrete a minimum of 12 inches thick. Reinforced steel, wire, or fiberglass fabric is also required in this concrete pour. (See Figure 13.22.) The concrete is used to provide a level and solid foundation for the wall. The concrete should be wet enough that the rocks will partially sink into it but stiff enough to support them. Before rocks are used in the retaining wall, thoroughly wire brush and wash the rocks with water to create a clean surface to which the concrete and mortar will readily adhere. Muriatic acid is sometimes used to clean oily or dirty rocks. When foundation rock is placed on the wet concrete, any irregularities on the bottom of the rock are filled and supported. Good contact between rocks is still required, but full contact is not as critical as any gaps between the rocks will be filled with mortar. The rock selection process is the same as for dry wall construction. The shaping of rock with specialized tools is similar, but less critical as mortar can be used to fill the gaps and provide contact.

Before the next tier of rock can be laid, some form of drainage to allow water to drain through or around the wall must be installed, since any gaps in the wall are filled with mortar. Drainage can be accomplished by installing a curtain drain that directs water from behind the wall to the outside edges, or with sections of PVC pipe that extend from the porous backfill to the face of the wall. Figure 13.23 provides basic specifications for the construction of a curtain drain.

The second tier of rock is installed in a similar fashion as for dry stone masonry. Once several rocks or the entire tier of rocks that fit together well have been selected and shaped to provide good contact, they are wiped with a damp cloth or sponge so that the dry rocks will not pull the moisture out of the mortar, causing the mortar to fail prematurely. A thin layer of mortar is troweled on top of the foundation rocks to provide a bed for the next tier and provide good contact between the rocks of the two tiers. Use a thicker layer where there are voids and poor contact.

Another layer of mortar is applied to the bottom of the second tier rock before it is set on the foundation tier. Once this rock is set on top of the first tier, it is gently tapped with the butt of the trowel until it is firmly sitting on the bottom tier and rock to rock contact is achieved. Excess mortar that is squeezed out from between the two tiers is scooped up with the trowel. If the excess mortar is uncontaminated, put it back on the mortarboard. Contaminated mortar can be used to fill gaps behind the rock just placed.

Mortar is then troweled on the side of the rock where the next one will butt against it. Again, apply a thin layer where there is good contact between rocks and a thicker layer where there are gaps. The next rock is set in the same manner as the first, except mortar is troweled on the side that will butt against the rock previously laid. The second rock is then pressed against the preceding rock and gently tapped with the butt of the trowel until rock to rock contact is made on the bottom and side. Any excess mortar squeezed out during this process is treated as described previously.

This process continues until the second tier is complete. (See Figure 13.23.) As the tiers of a mortar retaining wall are constructed, they need to adhere to the set back and batter requirements as for a dry stone retaining wall. The joining of separate walls, alternate overlapping of corners, the final wall elevations, and tread finishing previously discussed also apply.

13.13.2. Finishing

There are many styles of finish for wet masonry rock walls. If there is a distinctive architectural style for the area, follow this style unless planning, environmental review, or permits dictate otherwise. The finishing styles fall into two basic categories - hidden mortar and exposed mortar. The hidden mortar style looks the same as a dry stone wall. All of the mortar is applied behind the wall face where it cannot be seen. This style requires tighter fitting rocks, especially toward the front. The mortar helps compensate for irregularities and gaps behind the face of the wall. The exposed mortar wall has mortar visible between the sides, tops, and bottoms of the rocks. Exposed mortar also has many architectural styles, which have differing thicknesses, widths, finishing, and tooling. Specialized tools are used to create the final appearance of the mortar (“tool out”) so that it is either recessed or extruded. Additives can be included in the mortar mix to alter its color. Concrete color additives or lampblack are often used to soften the appearance of the wall or match the mortar to previously installed walls.

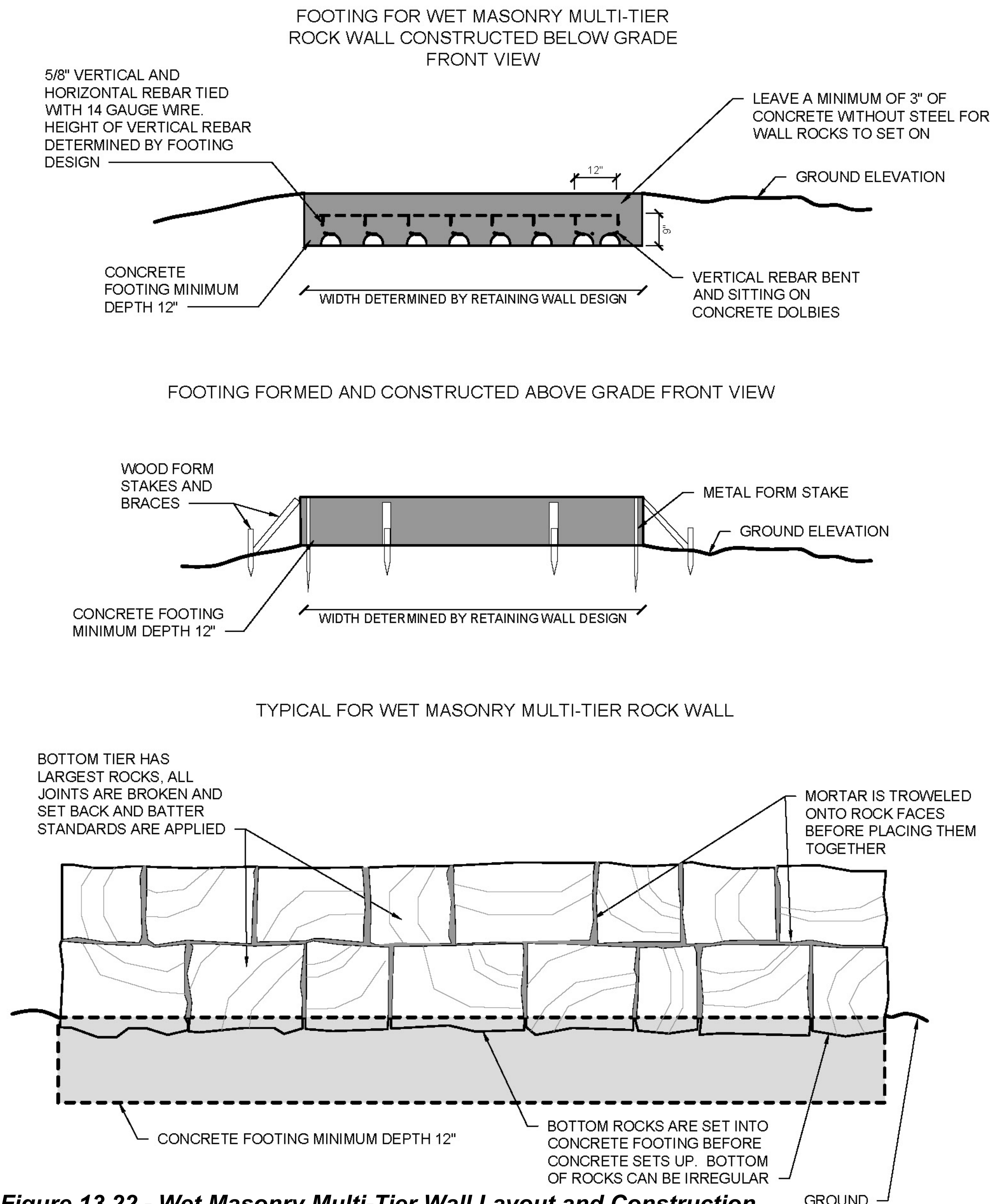


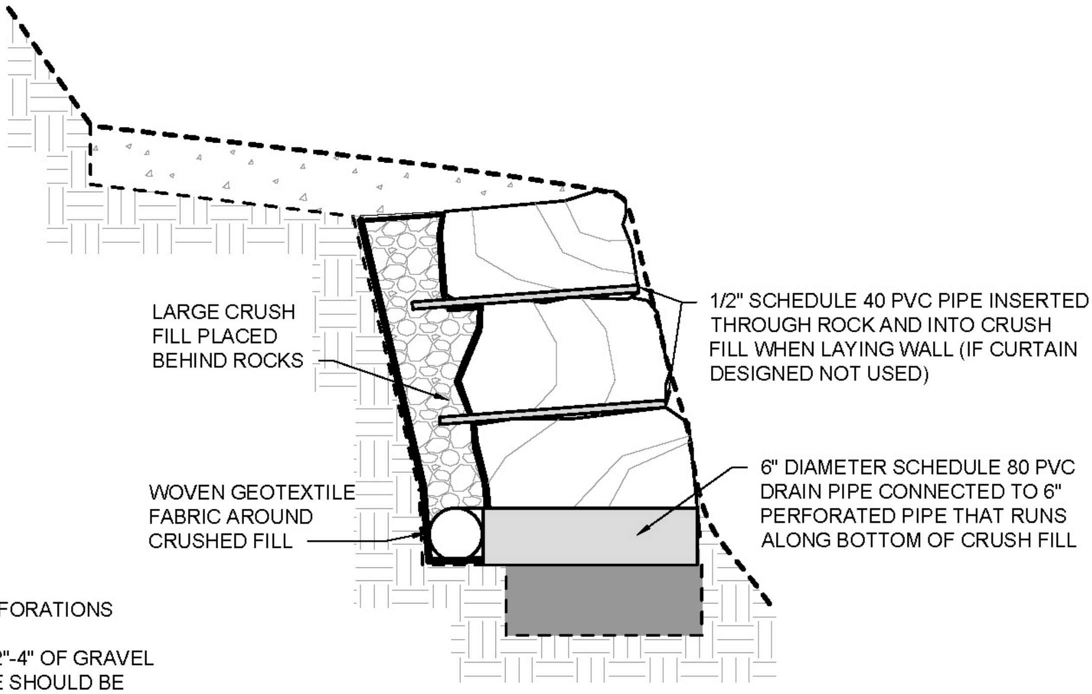
Figure 13.22 - Wet Masonry Multi-Tier Wall Layout and Construction

WET MASONRY MULTI-TIER WALL LAYOUT AND CONSTRUCTION

CALIFORNIA STATE PARKS

NOT TO SCALE

CURTAIN DRAIN AND PVC PIPE DRAIN DETAILS (END VIEW)



NOTES:

1. PLACE PIPE PERFORATIONS FACING DOWN
2. PLACE PIPE ON 2"-4" OF GRAVEL
3. PIPE DISCHARGE SHOULD BE DIRECTED TO LOCATIONS THAT AVOID EROSION AROUND THE WALL FOUNDATION

CURTAIN DRAIN AND PVC PIPE DRAIN DETAILS (FRONT VIEW)

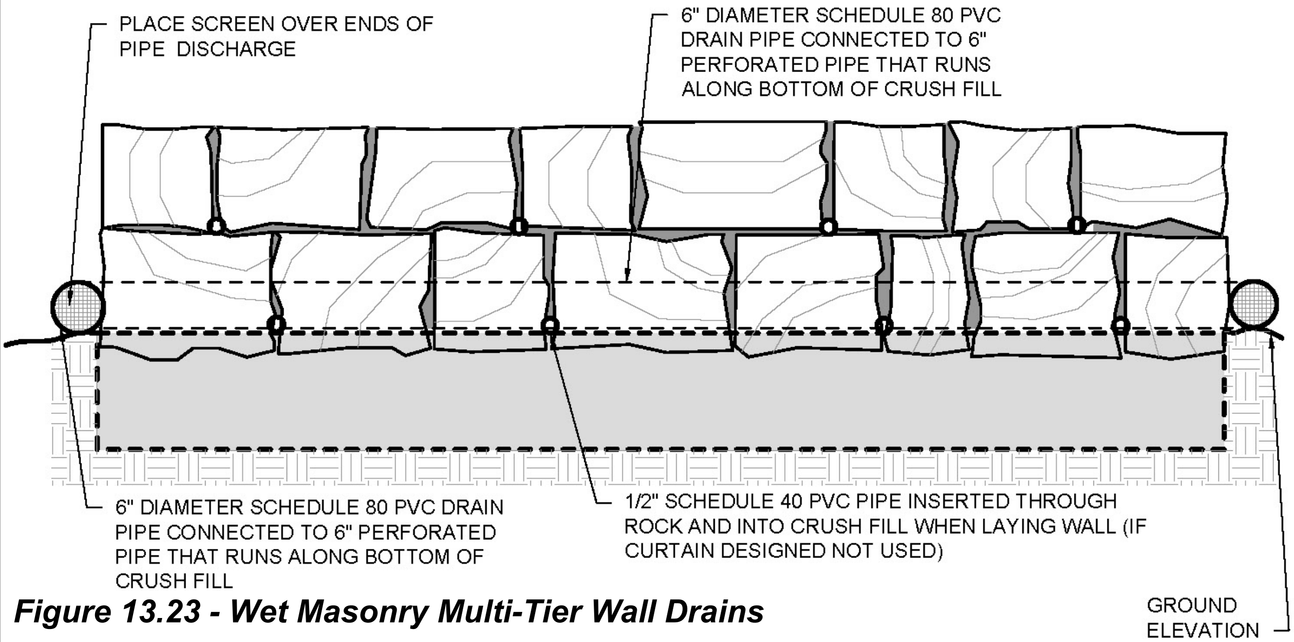


Figure 13.23 - Wet Masonry Multi-Tier Wall Drains

WET MASONRY MULTI-TIER WALL DRAINS

CALIFORNIA STATE PARKS

NOT TO SCALE

Regardless of the style, once the rock has been set and tooled out to the desired finish, a wet sponge is used to wipe off any excess mortar and clean the exposed rock faces. Sometimes a mild acid wash (vinegar) is applied to the wall after the mortar has set, to soften the appearance of the rock and give it a more aged look (patina). Fish oil emulsions and native moss spores can also be applied to expedite the softening and naturalizing of the wall's appearance.

13.14. Soldier Pile Retaining Walls with Timber Lagging

13.14.1. Applications

Soldier pile retaining walls stabilize the trail bed and back slopes, retain fill material below the trail, serve as approach ramps to bridge structures, and retain fill used to bridge over tree roots and rocks. (See Photo 13.15.) These structures are constructed using vertical H beam posts, horizontal wall boards, slotted channels, ground anchors, and threaded steel rods. They can be engineered using a variety of designs and materials. Once designed by an engineer, the retaining wall components must be fabricated and purchased. To eliminate the design costs and simplify acquisition of the wall components and wall construction, a commercially available pre-engineered and prefabricated soldier pile retaining wall may be selected. This type of solider pile retaining wall system is discussed below. However, site specific and engineered soldier piles walls may be required.

Photo 13.15 - Soldier Pile Retaining Wall

13.14.2. Attributes

These walls do not require advanced skills to assemble and are effective at retaining and containing low to moderate amounts of fill. They can be used to buttress unstable back slopes and stabilize the trail bed. They can also be used to retain fill material below the trail and on steep side slopes, thereby reducing trail bed and back slope excavations. A small workforce with mechanized equipment can transport and assemble the structures relatively quickly. Under the right circumstances, soldier pile walls can be very cost effective.

13.14.3. Limitations

Soldier pile walls require mechanized tools (gas powered or hydraulic) to set the H beam posts and install the ground anchors. Not all trail programs have the tools to support the installation of these structures, and some wilderness areas prohibit their use. Depending on the height of the wall, the length of the H beam post, and the slope of the ground, driving the post into ground may be difficult. The architectural design and aesthetic qualities of these structures may also not be appropriate in some locations.

Since the wall boards represent the largest portion of the structure and are usually comprised of pressure treated wood, the structure has a relatively short life span. Structural grade plastic wood can be used for the wall boards, which will provide more longevity. However, plastic wood has some aesthetic drawbacks and should not be used where it is exposed to direct sunlight.

When using a soldier pile retaining wall in a coastal environment the standard steel or all weather steel H beam posts and metal caps will rust and deteriorate in the salt air. In this environment, only galvanized steel or aluminum H beam posts and wall caps should be used. Again, these materials may have some aesthetic drawbacks.

13.14.4. Construction

In some situations, soldier pile designs do not require an excavated foundation, since 1-inch rebar and the H beam post are driven into the ground and the wall is held in place by ground anchors. This installation method works if the ground is stable. However, if the retaining wall is being used to stabilize an unstable slope with several feet of loose unconsolidated soil, the rebar and H beam post must be driven into stable ground to be effective, which could be difficult, depending on the depth they need to be driven into the ground. Due the height of the rebar and H beam post, trail workers may not be tall enough to hold them and still control the power or hand tools required to drive them in the ground. Scaffolding may be required to provide the workers with the elevation necessary to perform this operation. In this case, it may be more efficient to excavate a footing into the slope, so that the rebar and H beam post can be driven into stable earth without workers having to reach over their heads. When soldier pile retaining walls are used to stabilize the back slope or contain soil on a steep hill slope to reduce trail bed and back slope excavation, a footing is rarely required.

Prior to construction, the size and height of the wall must be determined. These dimensions depend on the area to be contained and the steepness of the slope where the retaining wall will be built. The height or length of the H beam post depends on how deep into the earth it will be driven and the height of the retaining wall. The number of H beam posts needed depends on the length of the wall and the layout or frequency of the posts along the wall. Most commercially available soldier pile retaining walls have a maximum spacing of 5 feet on center for the H beam post.

The wall boards are usually 2- x 6-inch or 2- x 8-inch pressure treated Douglas fir, which is ordered from the manufacturer at the finished length so they will not have to be cut. Pre-cut finishes will increase their life span. Once pressure treated lumber is cut, it will not last as long as uncut wood even if later painted with a wood preservative. Many vendors sell pressure treated lumber. Some manufacturers provide a selection of colors (brown, green, or gray) in pressure treated products. Color preferences should be noted when the order is placed. Structural grade plastic wood can also be ordered in different colors. It can be cut to length in the field as the cut ends are not subject to rot.

The number of boards depends on the total square footage of the retaining wall to be constructed. Allow at least one ground anchor for each H beam post. These are typically duck billed anchors for soft soil, and expansion anchors for rocky conditions. Anchors are attached to the post with threaded steel rods and nuts. (See Figure 13.24.) The H beam post is manufactured in heights from 2 feet to 10 feet. Walls exceeding 4 feet must be engineered. Duck billed anchors, expansion anchors, and threaded steel rods and nuts can be purchased from most hardware vendors. Note, in coastal areas it is advisable to use galvanized or aluminum H posts, stainless steel fasteners, duck bill anchors, all thread, nuts, and wire rope because they won’t corrode quickly in the salty environment.

Tools and equipment needed to install these walls include hand tools such as picks, Pulaskis, axe (cutter) mattocks, shovels, double jacks, and high lift jacks. In addition, a hydraulic hammer or a gas powered hammer is required to drive the rebar and H beam post into the ground and the anchors into the soil. Hydraulic or gas powered drills are used to install the rebar and expansion anchors into rock. When rock is encountered, two-part epoxy glue is required to anchor the rebar into the rock. The H beam post will slide over the top of the rebar. When hydraulic tools are used, a portable hydraulic power unit also is necessary. Some mechanical trail dozers and excavators have hydraulic power units that can also be used for this purpose. Gas powered hammers and drills, such as ponjars, picos, or cobras, can drill into rock or drive the H beam post into the ground. With the aid of a generator, electric powered roto-hammer drills can be used for drilling into rock. Wrenches and socket sets are also required to attach the threaded steel rods and nuts to the H beam post. Electric and battery powered drills are needed to attach the metal cap to the top of the retaining wall.

The general layout process previously described is followed to determine the starting and ending elevations of the retaining wall. However, soldier pile retaining walls are vertical and have no batter. The soldier pile retaining wall design used in this handbook has a maximum non-engineered height of 4 feet.

Alternatively, a stepped wall can be constructed. This structure consists of one wall constructed on top of another. The second wall should be set back from the front of the first wall a minimum of 2 feet. If this structure is used, then the layout must compensate for the setback of the second wall. Once the layout is complete and the locations for the H beam posts are identified, a 45 to 50 pound hydraulic or a gas powered hammer with a rebar driver attachment is used to drive 1-inch diameter rebar 3 to 4 feet long into the ground. The H beam post is set over the rebar, with the rebar sliding into the channel in the center of the post. Using a driver attachment fabricated for the H beam post, the post is driven 2 feet into the ground, or until the finished elevation is achieved at the top of the post. (See Figure 13.24.) A string line is set to identify this elevation and as a guide for the trail workers. In very soft soil it may be possible to use a fabricated manual post driver weighing approximately 40 to 50 pounds to drive the H beam post into the ground

If the retaining structure will be anchored into rock, then a hydraulic, gas, or electric powered drill is used to drill a hole 1 1/8 inches in diameter and 12 inches deep. This hole is cleaned of rock dust, and two-part epoxy glue is squeezed into the hole. One glue package is sufficient for this application. A piece of rebar 1-inch in diameter and 2 to 3 feet in length is driven into the hole until it is fully seated. The H beam post is then placed over the rebar. (See Figure 13.24.)

When the first post is set, wall boards of 2- x 6-inch or 2- x 8-inch and 4 to 5 feet long are placed into the slot on the side of the H beam post. These boards will show the placement of the next H beam post, as they must fit into the channel or slot on its side. Once the location of the next H beam post is identified, the process is repeated. After two posts are installed, the wall boards can be dropped into the slots on the sides of the posts. If the ground between the posts has not been leveled prior to installation, it may be necessary to do so before the first (bottom) board is installed. (See Figure 13.24.) The starting elevation where the first board will sit must be consistent with the layout, as it will affect the final elevation of the wall. It is also important to provide a gap between the boards for drainage. The height of the gap in the wall may vary, depending on the anticipated drainage from behind the wall. A 1/2-inch gap between the boards is considered the minimum with a 1-inch gap being preferred. This gap can be established by inserting a piece of metal stock between the wall boards where they set on top of each other inside the post channel. (See Figure 13.24.)

On soft soil, a hydraulic or gas powered hammer with a gad drive attachment is used to drive an earth anchor (duck billed anchor) into the hill slope behind the wall once the wall boards are installed. The duck billed anchors should have a minimum 3,000-pound capacity. The anchors are driven into the hill slope a minimum of 4 to 6 feet. Use anchors that are designed to attach to 1/2-inch diameter all thread. The all thread is attached to a high lift jack and the jack is used to pull on the all thread and set the duck billed anchor. Setting the duck billed anchor requires pulling it several inches to open the bill. The all thread is run through a hole in the H beam post and attached with nuts and washers. The holes can be pre-drilled, or drilled on-site if the appropriate power tools are available, and placed within 12 inches of the top of the post to provide good leverage once the wall is loaded. (See Figure 13.24.) Commercially available soldier pile walls will already have these holes drilled through the posts. The all thread is tightened until the wall is pulled two to three degrees past vertical into the hill slope. Once backfilled, the weight of the backfill will push the wall out to where it is nearly plumb.

When setting anchors in rock, use a hydraulic or gas powered rock drill to drill a 5/8-inch diameter hole a minimum of 3 inches deep into competent rock. Insert an expansion anchor into the hole and set it with a setting tool. (See Figure 13.24.) Use an anchor that can be attached to a half inch all thread, and attach the all thread to the posts as described above.

When the anchors are set, 2-inch channel iron is installed on top of the final wall board and H beam posts to provide a metal cap. The channel iron is pre-cut to length matching the center spacing between the posts, and placed on the wall so that it spans from the center of one H beam post to the center of the next. An electric, gas, or battery powered drill is used to drill a 3/16-inch hole through the channel iron into the post. A 1/4- x 1-inch metal screw fastens the channel iron to the post. This screw can be installed with an electric, gas, or battery powered drill. (See Figure 13.24.)

Once the metal cap is installed, the retaining wall can be backfilled with porous material that allows water to pass through to the front of the wall, where it can seep out through the gaps left in the wall boards. A minimum of 4 inches of fill consisting of the desired tread material is installed on top so that the designed surface drainage is achieved.

13.15. Geotextile Fabric Retaining Walls

13.15.1. Applications

Geotextile fabric walls are used to stabilize the trail bed and retain fill material below the trail and bridge over tree roots and rocks. (See Photo 13.16.) The fabric is made from synthetic fibers that are bonded together and woven or heat-bonded to form a strong and pliable material. These structures use the weight of the earthen material contained within the fabric, minor pinning, and friction between the layers of fabric to contain and unitize the fill material.

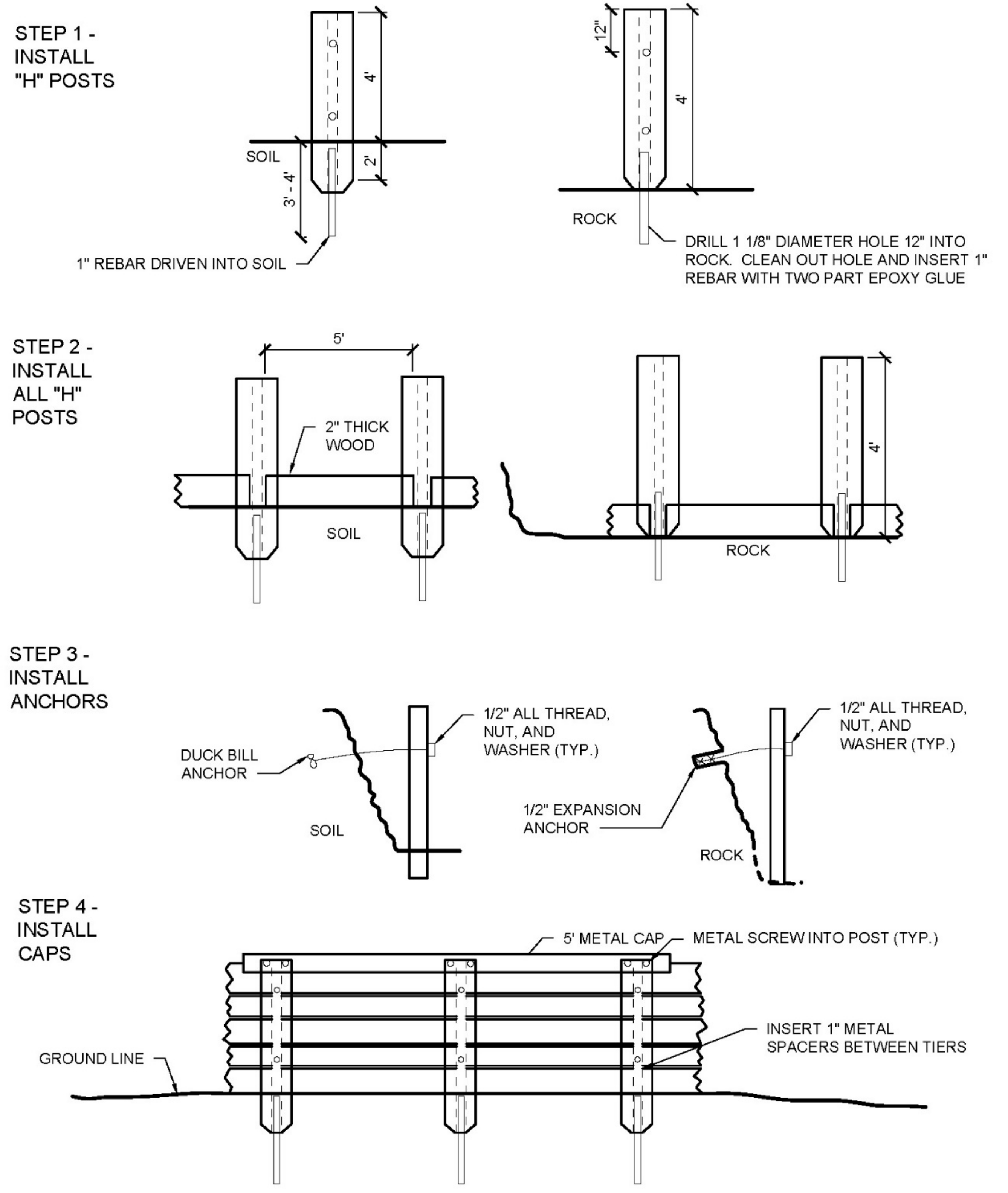


Figure 13.24 - Soldier Pile Retaining Walls

SOLDIER PILE RETAINING WALLS

CALIFORNIA STATE PARKS

NOT TO SCALE

Photo 13.16 - Geotextile Encapsulated Wall

13.15.2. Attributes

These structures are the simplest of all multi-tier retaining walls to construct. They require very little in the way of skills and tools. Geotextile fabric is lightweight, easily transported over long distances, and effective at retaining low to moderate amounts of fill, stabilizing fill material below the trail, and containing fill to bridge over rocks and tree roots. A small workforce can transport this material and assemble this structure quickly. Since geotextile walls have only been in use for thirty years, it is difficult to determine their life span. If not exposed to ultraviolet light, these structures should last decades. Considering the low price of the fabric and the simplicity of construction, they are the most cost effective multi-tier retaining structure.

13.15.3. Limitations

Certain land management regulations, such as those applied to wilderness areas, prohibit synthetic materials. The architectural design and aesthetic qualities of geotextile structures may not be appropriate in some locations. If not covered with soil and re-vegetated, these materials are unsightly and quickly deteriorate due to ultraviolet light exposure. The topsoil, organics, and vegetation covering the face of the wall are difficult to retain if the face of the finished retaining wall has a slope of greater than 45 degrees. In some locations, re-vegetation may be too slow to consider use of this structure. Geotextile structures are not very permeable and should not be used in locations where water can be trapped behind the retaining wall. Due to the size of the foundation required for these structures and the maximum 45 degree wall face suggested for soil and vegetative covering, these structures are usually limited to hillslopes of 35 degrees (if the wall face extends beyond the existing slope) or 45 degrees (if the wall face matches the existing slope). (See Figure 13.25.) However, if required, a wall face steeper than 45 degrees may be achieved if the face of the wall is covered with rock rather than soil. A non-structural rock facing is the most stable at angles steeper than 45 degrees.

13.15.4. Synthetic and Gabion Retaining Wall Layout

Synthetic and gabion retaining walls require a substantial foundation. This foundation must accommodate the retaining wall structure and the soil, organics, and vegetation installed on the front of the wall to hide the synthetic/gabion materials, protect plastic or petroleum-based materials from ultra-violet light, and blend the wall with its natural surroundings.

Prior to prescribing the use of a synthetic or gabion retaining wall, it is prudent to determine if the angle of the hillslope the retaining wall is to be constructed upon is suitable. This determination can be quickly accomplished by sighting the angle of the hillslope with a clinometer. (See Chapter 5, *Principles of Trail Layout and Design*, for further information on using clinometers to identify slope gradients.) If the finished face of the retaining wall will not project beyond the existing hillslope, the angle of the existing hillslope should not be more than 45 degrees. If the finished face of the retaining wall will project beyond the existing hillslope, the angle of the existing hillslope should not be more than 35 degrees. (See Figure 13.25.)

Once the angle of the hillslope is determined to be suitable, the first step in the layout process is to identify the trail bed elevation by placing a pin flag where the inboard hinge of the trail bed will be located. This elevation will be site specific. (See Figure 13.25.) Next, identify the designed trail bed width. Again, this width will be site specific. **For the example in Figure 13.25 the trail bed width is 6 feet.** Once the bench width is determined, add 2 feet for the soil covering the face of the wall (6 ft. + 2 ft. = 8 ft.). Next, estimate the starting point/elevation of the retaining wall foundation on the hillslope and place a pin flag at that location. The retaining wall foundation must be on firm and stable ground and capable of supporting the weight of the wall and trail.

Next, install a horizontal string line starting at the elevation of the finished trail bed. This starting point will be at the base of the pin flag marking the inboard hinge of the intended trail bed. Drive a 40d or 50d nail into the ground at that location and tie a string line to the nail at ground level. Then, attach the other end of the string line to a pole of sufficient height to achieve a horizontal and level line beyond the starting point (pin flag) of the wall foundation. The string line may also be held by a coworker instead of attaching it to a pole. Regardless of the chosen method, two people are required. (See Figure 13.26.) Attach a line level to the string and adjust the line as necessary to achieve levelness. To determine the vertical distance from the horizontal string line (V) to the start of the wall foundation (pin flag), attach a plumb bob to another string line. Then, place the tip of the plumb bob at the base of the pin flag marking the start of the wall foundation and raise the string line to where it intersects with the horizontal line previously installed. Lift the string line upward so the plumb bob just barely lifts off of the ground. It may be necessary to move the string line attached to the plumb bob inward or outward along the horizontal string line until the vertical string line is plumb or at a right angle to the horizontal string line. Once the string is plumb, mark the horizontal string line where the two lines intersect with a felt tip marker. Measure down from the mark on the horizontal string line to the start of foundation (base of the pin flag) below to establish an initial vertical (V) measurement (e.g., 72 inches in this example). To determine the horizontal distance (H), measure from the trail bed elevation flag to the vertical reference mark previously established (e.g., 14 feet in this example). Subtract the combined width of the trail bed and the 2-foot bench needed for the wall covering material from this measurement (e.g., 6 ft. + 2 ft. = 8 ft.; 14 ft. - 8 ft. = 6 ft. or 72 in). There are now two distance measurements - the vertical (V) (72 inches) and the horizontal (H) (72 inches). (See Figure 13.26.)

If it is not possible to measure distances V and H with single measurements due to the height of the wall, an intermediate station can be used. This process is similar to the layout process previously described for laying out steps. (See Chapter 17, *Trail Steps*.)

If the horizontal distance (H) is equal to the vertical distance (V), then the fill slope angle is equal to 45 degrees. With a 45-degree angle, further adjustments are not necessary because the wall covering material will be stable.

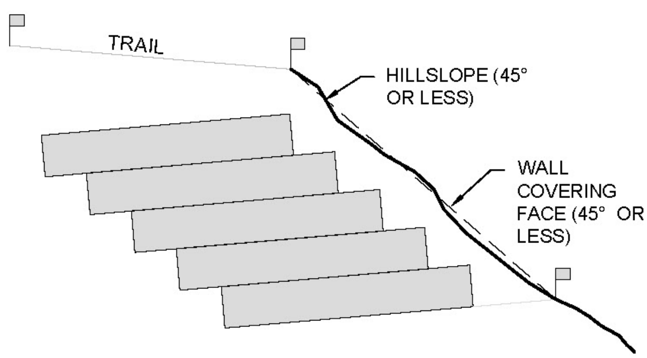
If the horizontal distance (H) is greater than the vertical distance (V), then the fillslope angle will be less than 45 degrees. Again, further adjustments are not necessary, because the wall covering material will be stable.

If the vertical distance (V) is greater than the horizontal distance (H), then the fill slope angle is greater than 45 degrees. Since it is difficult to stabilize the wall covering material at angles greater than 45 degrees, it may be necessary to cover the face of the retaining wall with angular rock. With this application, large rocks (>200 pounds) are placed in an excavated footing within the 2-foot landing provided for the wall covering material. The footing keeps the rock from sliding down slope and the large rock is used to buttress the rock placed on top of it. As the rock facing is placed, each layer should become successively smaller in size and there should be a minimum of three points of contact between each rock. This type of wall covering has limited applications and if the angle of the wall face is too steep, another retaining wall design should be considered.

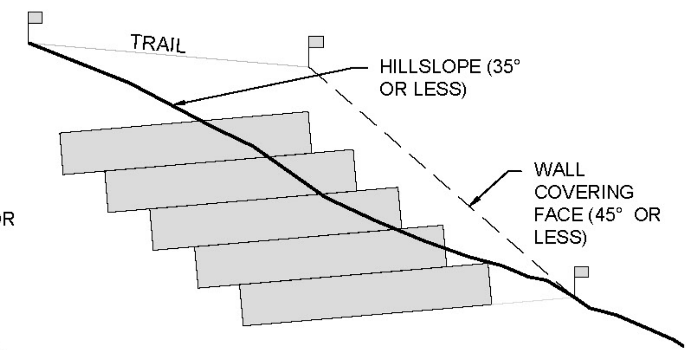
SLOPE ASSESSMENT

WHEN EVALUATING A NEW OR EXISTING TRAIL TO DETERMINE THE USE OF GEOSYNTHETIC OR GABION RETAINING WALLS IT IS IMPORTANT TO KEEP THE FINISHED ANGLE OF THE WALL FACE TO 45 DEGREES OR LESS. A QUICK WAY TO DETERMINE THE ANGLE IS TO SIGHT THE HILLSLOPE WITH A CLINOMETER. IF REPLACING THE EXISTING HILLSLOPE MATERIAL (FINISHED FACE OF THE RETAINING WALL MATCHES THE EXISTING HILLSLOPE) THE MAXIMUM HILLSLOPE ANGLE IS 45 DEGREES. If THE RETAINING WALL IS TO BE CONSTRUCTED BEYOND THE EXISTING HILLSLOPE THE MAXIMUM HILLSLOPE ANGLE IS 35 DEGREES. IF A 45 DEGREE OR LESS WALL FACE ANGLE CANNOT BE OBTAINED THEN THE WALL COVERING MATERIAL SHOULD ENSURE SUSTAINABLE COVERAGE OF THE WALL, OR ALTERNATIVE RETAINING WALL DESIGNS SHOULD BE CONSIDERED.

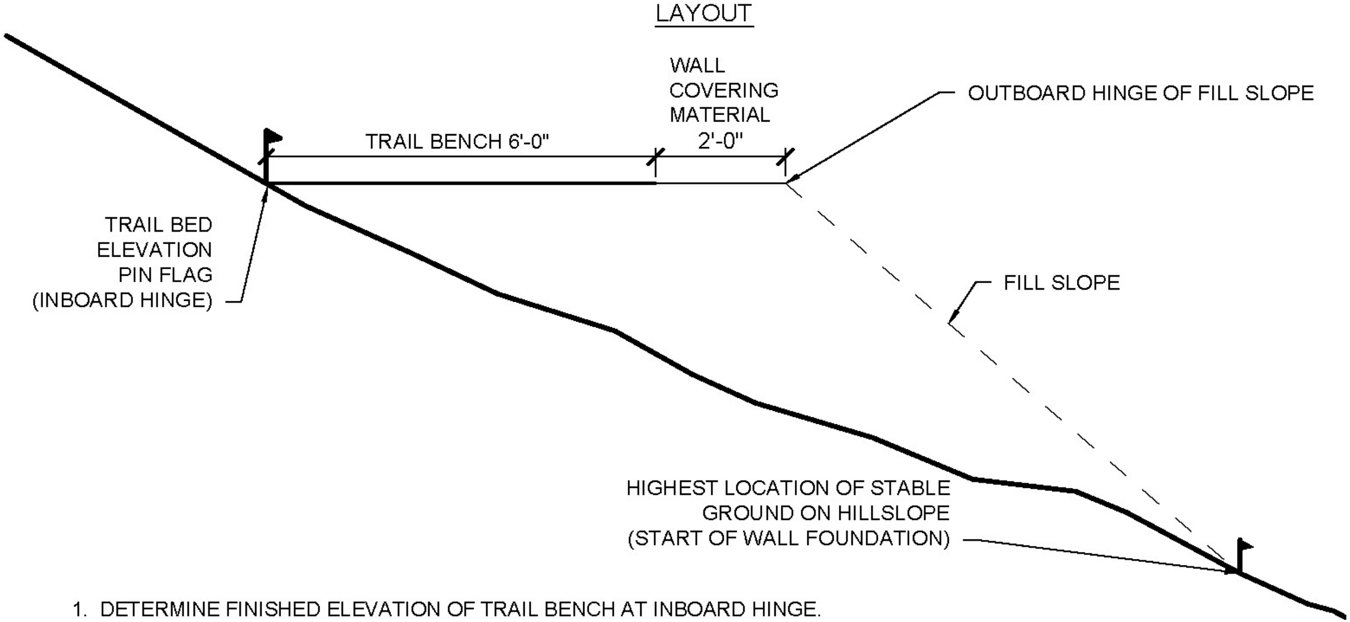
REPLACING EXISTING HILLSLOPE



CONSTRUCTING BEYOND EXISTING HILLSLOPE



LAYOUT



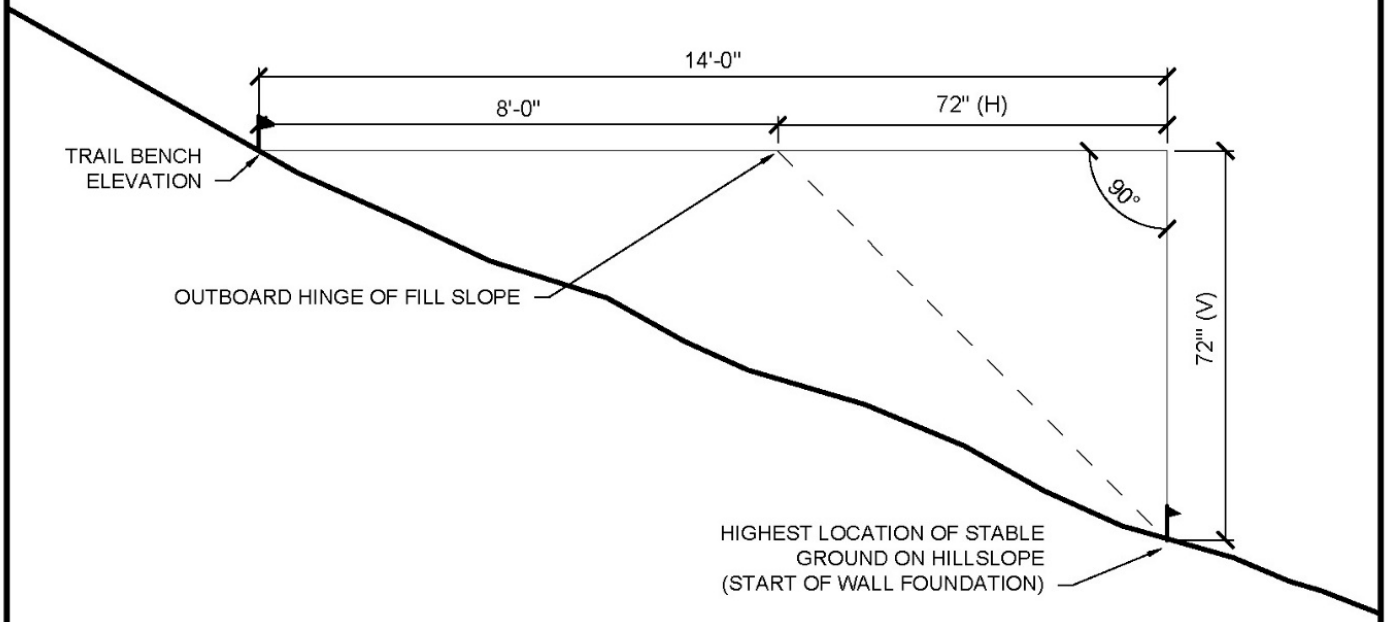
1. DETERMINE FINISHED ELEVATION OF TRAIL BENCH AT INBOARD HINGE.
2. DETERMINE REQUIRED WIDTH OF TRAIL BENCH (6').
3. ADD 2' TO TRAIL BENCH WIDTH (6') TO ACCOMMODATE NECESSARY MATERIAL COVERING THE FACE OF WALL (6'+2'= 8').
4. PLACE FLAG AT HIGHEST HILLSIDE LOCATION WHERE SOILS ARE CAPABLE OF PROVIDING A STABLE WALL FOUNDATION.

Figure 13.25 - Layout of Synthetic Material and Gabion Retaining Walls

LAYOUT OF SYNTHETIC MATERIAL AND GABION RETAINING WALLS

CALIFORNIA STATE PARKS

NOT TO SCALE



1. TO DETERMINE MEASUREMENTS INSTALL A HORIZONTAL STRING LINE STARTING AT TRAIL BENCH ELEVATION AND EXTEND IT PAST THE START OF WALL FOUNDATION FLAG. USE A LINE LEVEL TO ESTABLISH THE HORIZONTAL STRING LINE. TO DETERMINE DISTANCE V PLACE A PLUMB BOB AT THE START OF FOUNDATION FLAG AND MARK THE LOCATION, ON THE HORIZONTAL STRING LINE, WHERE THE HORIZONTAL STRING LINE AND PLUM BOB STRING INTERSECT. MEASURE FROM THE MARK ON THE HORIZONTAL STRING LINE DOWN TO START OF WALL FOUNDATION FLAG TO DETERMINE DISTANCE V (72"). TO DETERMINE DISTANCE H MEASURE FROM THE TRAIL BENCH ELEVATION ALONG THE HORIZONTAL STRING LINE TO THE HORIZONTAL STRING LINE MARK (14'). SUBTRACT TRAIL BENCH AND MATERIAL COVERING THE WALL WIDTHS (8') FROM THIS MEASUREMENT (14'-8'= 6' OR 72").

2. IF DISTANCE H IS EQUAL TO DISTANCE V THEN THE WALL FACE AND FILL SLOPE ANGLE ARE EQUAL TO 45°. IT IS NOT NECESSARY TO ADJUST THIS ANGLE AND BATTER AS WALL COVERING MATERIAL SHOULD BE SUSTAINABLE.

3. IF DISTANCE H IS GREATER THAN DISTANCE V THEN THE WALL AND FILL SLOPE ANGLE IS LESS THAN 45°. IT IS NOT NECESSARY TO ADJUST THIS ANGLE AND BATTER AS WALL COVERING MATERIAL SHOULD BE SUSTAINABLE.

4. IF DISTANCE V IS GREATER THAN DISTANCE H THEN THE WALL AND FILL SLOPE ANGLE ARE GREATER THAN A 45°. IF REASONABLY POSSIBLE ADJUSTMENTS SHOULD BE MADE TO LOWER THIS ANGLE , OR THE WALL COVERING MATERIAL SHOULD ENSURE SUSTAINABLE COVERAGE OF THE WALL, OR ALTERNATIVE RETAINING WALL DESIGNS SHOULD BE CONSIDERED.

Figure 13.26 - Layout of Syn. Material and Gabion Retaining Walls (Measuring)

LAYOUT OF SYNTHETIC MATERIAL AND GABION RETAINING WALLS
(MEASURING)
CALIFORNIA STATE PARKS
NOT TO SCALE

In some situations where the horizontal distance is less than the vertical distance, it may be possible to increase the horizontal (H) distance to equal the vertical distance (V) by moving the starting location for the wall foundation further down the slope. This application only works when the hill slope is less than 35 degrees. It should be noted that in moving the starting location for the retaining wall further down slope, the size of the retaining wall will be increased significantly. This option is really only practical on very shallow slopes. The further the foundation flag is moved down slope, the less viable this option becomes and another type of retaining structure should be considered.

Once the horizontal and vertical measurements are identified, determine the number of tiers required for the retaining wall. Subtract the height of tread material covering the wall (a desired depth of 12 in.) from the vertical measurement (e.g., 72 in. - 12 in. = 60 in.). Divide this figure by the desired height of each tier. In this example, if each tier is 12 inches high, there will be 5 tiers (e.g., 60 in. ÷ 12 in. = 5 tiers). (See Figure 13.27.) The height of the tiers may not divide evenly into the height of the retaining wall. If the desired height of the tiers is 8 inches (e.g., 60 in. ÷ 8 in. = 7.5 tiers) it may be necessary to increase the depth of the excavation by 4 inches to have the tiers come out evenly (e.g., 60 in. + 4 in. = 64 in.; 64 in. ÷ 8 in. = 8 tiers). If appropriate, the depth of the tread material covering the retaining wall could also be increased by 4 inches to create an even number of tiers. Again, this correction will be site specific.

The foundations for synthetic and gabion retaining walls are insloped at a 10% downward angle to transfer the weight of the wall into the hillslope. This 10% angle lowers the surface of the foundation approximately 1 inch for every 12 inches of run (i.e., 12 in. x 0.10 = 1.2 in.). The 1.2 inches is rounded down to 1 inch to simplify the layout calculations.

Since the first tier of the retaining wall begins 24 inches back from the face of the wall due to the inset needed for the wall covering material, the front of the first tier of the retaining wall will be 2 inches lower (i.e., 24 in. x 1 in. per 12 in. = 2 in.) than the front of the wall covering inset (start of retaining wall foundation flag). In addition to lowering the surface of the foundation, the 10% downward inslope also reduces the height of the wall face by approximately 1 inch for every 12 inches of height. In Figure 13.27, the vertical wall height is 60 inches once the 12-inch depth of the trail tread material is subtracted from the initial 72-inch vertical measurement. With a loss of 1 inch for every 12 inches of wall height, the actual height of the retaining wall face is 5 inches lower than calculated (i.e., 60 in x 1 in. per 12 in. = 5 in.). When the 2-inch loss of height from the wall covering inset is added to the wall height loss of 5 inches from the 10% foundation angle, the overall wall height is 7 inches less than V (72 in.).

This elevation difference should not affect the wall batter as it is partially offset by the outsloping of the trail tread and altering the depth of the trail tread material. However, retaining walls exceeding 12 feet in height may require that an additional tier be added to compensate for the cumulative elevation loss.

To determine the wall batter, measure the horizontal distance from the front of the bottom tier of the retaining wall to the original location of the outboard hinge of the fillslope (location of the combined width of the trail bench and wall covering material). In Figure 13.27 this distance is 48 inches. The wall batter should place the front edge of the top tier of the retaining wall directly under the outboard hinge of the fill slope. The 10% downward slope of the foundation will cause the face of the retaining wall to move into the hillslope 1.2 inches for every 12 inches of vertical rise in the wall. The 1.2-inch measurement is not rounded down to 1 inch when calculating the wall batter to ensure that the top front of the retaining wall is directly under the outboard hinge of the fill slope.

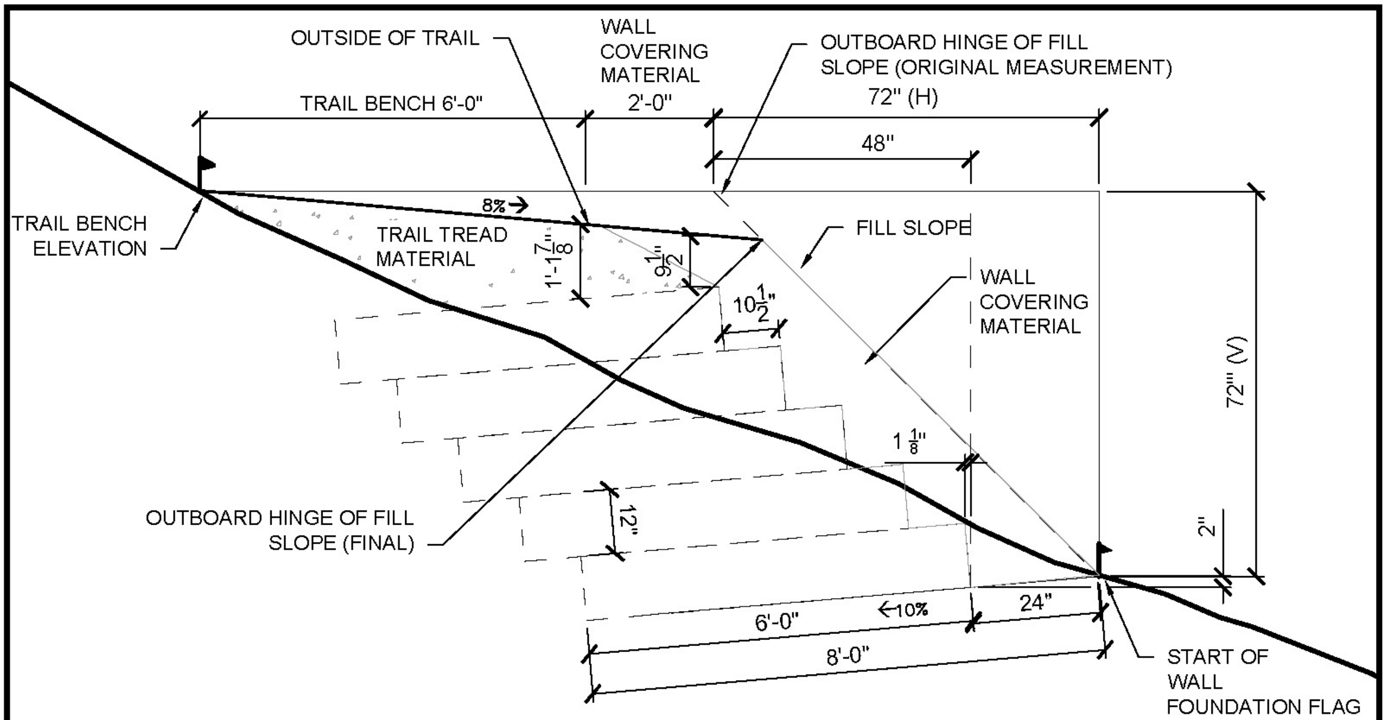
To calculate the total batter of the wall, multiply the number of 12-inch vertical rises in the retaining wall (5) by 1.2 inches (10% foundation slope correction) and then subtract this amount from the horizontal distance from the front of the bottom tier of the retaining wall to the outboard hinge of the fillslope (i.e., 60 inches ÷ 12 inches = 5 rises, 5 rises x 1.2 inches per rise = 6 inches, 48 inches planned horizontal distance – 6 inches = 42 inches actual horizontal distance). Then divide this number by the number of wall tiers minus one since the first tier has no batter (i.e., 5 -1 = 4, 42 inches ÷ 4 tiers = 10 1/2 inches per tier). Each wall tier after the initial tier will have a batter (set back from the tier below it) of 10 1/2 inches.

Due to the 10% downward angle of the retaining wall's foundation, the tread material covering the final tier will not have a uniform height. It will be wedge-shaped with the back of the tread material thicker or higher than the front. This wedge shape will be exaggerated when the trail tread is outsloped.

After determining the height of each tier, the number of tiers required, the starting elevation of the retaining wall foundation, and the batter for each tier, the depth of the wall foundation (trail bed width plus width of material covering the face of the wall) is excavated into the hill slope (e.g., 8 feet). The foundation is excavated with a 10% downward slope toward the rear of the wall.

The front of the first tier of the wall is started 2 feet back from the start of foundation pin flag to provide the necessary support for the soil, organics, vegetation, and rocks (if used) covering the face of the wall. The final trail bed elevation is achieved by installing approximately 12 inches of tread material over the top of the retaining wall. The minimum tread depth over the top front of the final wall tier is 8 inches.

Note, the maximum tier height for a geotextile fabric wall is 12 inches. Other synthetic retaining wall materials, such as cellular confinement, come in 6- and 8-inch cell heights. Gabion baskets usually come in 1-foot increments with a typical trail application basket being 2 to 4 feet high.



1. SUBTRACT THE TREAD SURFACE MATERIAL (12") FROM V (72") TO DETERMINE THE APPROXIMATE HEIGHT OF THE WALL (72"-12" = 60"). THEN DIVIDE THIS HEIGHT (60") BY THE HEIGHT OF THE WALL TIERS (12") TO DETERMINE THE NUMBER OF TIERS (60"/12"= 5 TIERS). IF THE HEIGHT OF THE WALL TIERS DOES NOT DIVIDE EVENLY INTO THE WALL HEIGHT IT MAY BE NECESSARY TO INCREASE V AND/OR ADJUST THE DEPTH OF THE TRAIL TREAD MATERIAL UNTIL THE HEIGHT OF THE TIERS DIVIDE EQUALLY INTO THE WALL HEIGHT. THIS WALL HEIGHT CALCULATION DOES NOT ACCOUNT FOR THE HEIGHT DIFFERENCE BETWEEN V AND THE ACTUAL HEIGHT OF THE WALL DUE TO THE INSET FOR THE FOUNDATION OF THE WALL COVERING MATERIAL AND THE 10% DOWNWARD FOUNDATION SLOPE. THE ELEVATION DIFFERENCE CREATED BY THE WALL COVERING INSET IS APPROXIMATELY 1 INCH PER EVERY 12 INCHES BETWEEN THE START OF FOUNDATION WALL FLAG TO THE START OF THE FIRST TIER OF THE WALL. IN THIS EXAMPLE THE 24 INCH INSET WOULD CAUSE THE WALL TO BE 2 INCHES LOWER THAN V (24"/12"=2, 2 X 1"=2"). THE 10% DOWNWARD FOUNDATION SLOPE ALSO GENERATES THE SAME ELEVATION DIFFERENCE OF APPROXIMITELY1 INCH PER EVERY 12 INCHES OF WALL HEIGHT, BETWEEN V AND THE ACTUAL WALL HEIGHT. IN THIS EXAMPLE THE WALL (60") WOULD BE 5 INCHES LOWER THAN V (60"/12"= 5, 5 x1" =5") . IN THIS EXAMPLE THE TOTAL ELEVATION DIFFERENCE BETWEEN V AND THE ACTUAL HEIGHT OF THE WALL IS 7 INCHES (2" + 5" =7 "). THIS ELEVATION DIFFERENCE SHOULD NOT AFFECT THE WALL BATTER AND IS GENERALLY OFFSET BY THE OUTSLOPE OF THE TRAIL AND THE ABILITY TO ALTER THE THICKNESS OF THE TRAIL TREAD MATERIAL. A WALL EXCEEDING 12 FEET IN HEIGHT MAY REQUIRE THAT AN ADDITIONAL TIER BE ADDED TO COMPENSATE FOR THE SIGNIFICANT ELEVATION DIFFERENCE CAUSED BY THE 10% DOWNWARD FOUNDATION SLOPE . DUE TO THE 10% DOWNWARD ANGLE OF THE FOUNDATION, THE DEPTH OF THE TRAIL TREAD MATERIAL WILL ALWAYS BE GREATER TOWARD THE INSIDE OF THE TRAIL.

2. TO DETERMINE THE WALL BATTER, MEASURE THE HORIZONTAL DISTANCE FROM THE FRONT OF THE BOTTOM TIER OF THE WALL TO THE OUTBOARD HINGE OF FILL SLOPE (ORIGINAL MEASUREMENT). IN THIS EXAMPLE THAT MEASUREMENT IS 48 INCHES. THE BATTER SHOULD PLACE THE FRONT EDGE OF THE TOP TIER DIRECTLY UNDER THE OUTBOARD HINGE OF FILL SLOPE (ORIGINAL MEASUREMENT). THE 10% DOWNWARD FOUNDATION SLOPE WILL CAUSE THE FACE OF THE WALL TO MOVE INTO THE HILLSLOPE 1.2 INCHES FOR EVERY 12 INCHES OF VERTICAL RISE IN THE WALL. OFFSET THIS DIFFERENCE BY MULTIPLYING THE NUMBER OF 12 INCHES OF VERTICAL RISE BY 1.2 INCHES AND THEN SUBTRACT THIS AMOUNT FROM THE DISTANCE FROM THE START OF THE BOTTOM TIER OF THE WALL TO THE OUTBOARD HINGE OF FILL SLOPE (ORIGINAL MEASUREMENT) (60"/12"=5, 5 X 1.2"=6", 48"- 6" =42"). THEN DIVIDE THIS NUMBER BY THE NUMBER OF HORIZONTAL RUNS (SET BACKS) IN THE WALL (42" / 4= 10 $\frac{1}{2}$"). THE NUMBER OF RUNS WILL BE ONE LESS THAN THE NUMBER OF WALL TIERS (5 TIERS -1 = 4 RUNS). THUS EACH TIER WILL SET BACK 10 $\frac{1}{2}$" FROM THE ONE BELOW IT.

3. BEGINNING AT START OF FOUNDATION WALL FLAG, EXCAVATE THE FOUNDATION INTO THE HILLSLOPE BY AN AMOUNT EQUAL TO THE TRAIL TREAD WIDTH (6') PLUS THE WIDTH OF THE MATERIAL COVERING THE WALL (2') FOR A TOTAL OF 8 FEET. (NOTE FOUNDATION TO BE EXCAVATED AT A 10% DOWNWARD ANGLE).

4. PLACE THE FIRST WALL TIER 2 FEET BACK FROM START OF EXCAVATION TO ACCOMMODATE THE FOUNDATION NECESSARY TO SUPPORT THE MATERIAL COVERING THE FACE OF THE WALL.

Figure 13.27 - Layout of Syn. Material and Gabion Retaining Walls (Wall Batter)

LAYOUT OF SYNTHETIC MATERIAL AND GABION RETAINING WALLS

(DETERMINING WALL BATTER)

CALIFORNIA STATE PARKS

NOT TO SCALE

13.15.5. Construction

Geotextile fabric comes in a number of weaves and weights. When selecting fabric for a retaining wall, the fabric should be structurally sufficient to hold up to the rigors of wall construction and its intended use. Fabrics should have minimum grab strength of 120 pounds, a grab tensile elongation of 50%, and a Mullen burst strength test of 230 pounds per square inch. The fabric can be either woven or non-woven. The non-woven has more initial permeability, but will plug quicker than the woven fabric. However, neither is effective at passing water once clogged with soil or organics. Woven fabric is slick and provides less friction, making it difficult to work with during construction. The non-woven fabric is more pliable, and the felt-like finish makes it less apt to slip when folded back on itself, which is required in constructing geotextile walls. The non-woven fabric is the most user friendly.

In most trail applications, excavation of the foundation is performed with hand tools such as picks, axe (cutter) mattocks, Pulaskis, hazel hoes, and McLeods. Excavation can also be accomplished with a mini-excavator where appropriate or practical. Prior to digging, any vegetation suitable for transplanting is salvaged from the work area and kept in wet burlap sacks until it can be planted later in the soil placed over the face of the retaining wall. Once excavation begins, all organics and topsoil from the area are saved for later placement over the completed wall. Save all B horizon soil for use as backfill material. When excavating the foundation, the minimum rearward tilt into the hill slope is 10%. This tilt ensures that the weight of the wall is transferred into the hill slope. The excavation must not be longer than the length of the retaining wall. Vertical earthen sides will help retain the fill material placed on top of each fabric tier. (See Figure 13.28.)

Once the foundation is complete, construction of the wall begins. Geotextile fabrics come in rolls of 12, 16, and 20 feet. The length of the fabric should correspond with the width of the wall. If the retaining wall is 14 feet long (horizontally), add a minimum of 3 feet of fabric on each end of the wall to fold and seal off the backfill at the ends of the wall. (See Figure 13.28.) Thus, if the retaining wall will be 14 feet long, use fabric from a 20-foot roll. Unroll and cut off the length of fabric needed for one tier of the wall. For example, if the retaining wall will be 14 feet long and 6 feet high, the foundation of the wall needs to be at least 6 feet deep to achieve a 45-degree angle to the face of the wall. Each tier is 1 foot high and has two layers of fabric - one below the fill material and one above. For one tier, a piece of fabric is needed that is approximately 13 feet long: 6 feet for the bottom of the tier, 1 foot for the height of the tier, and 6 feet for the top of the tier. With a total of six tiers, approximately 78 feet of 20-foot wide fabric is needed. (See Figure 13.28.) If the retaining wall is longer than the fabric, additional lengths are cut and laid side by side with a minimum 4-foot overlap.

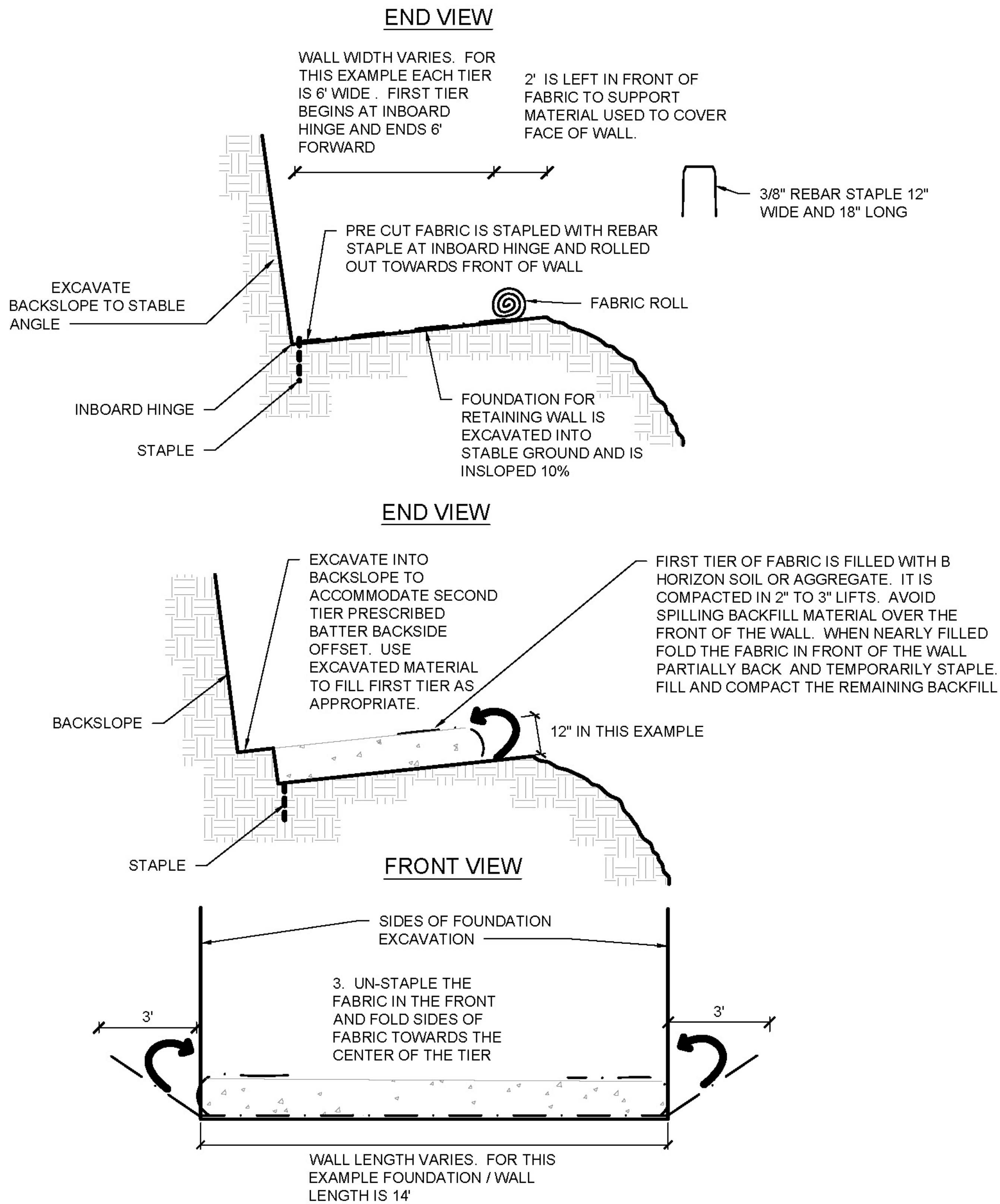


Figure 13.28 - Geotextile Fabric for Encapsulated Soil Walls

GEOTEXTILE FABRIC FOR ENCAPSULATED SOIL WALLS

CALIFORNIA STATE PARKS

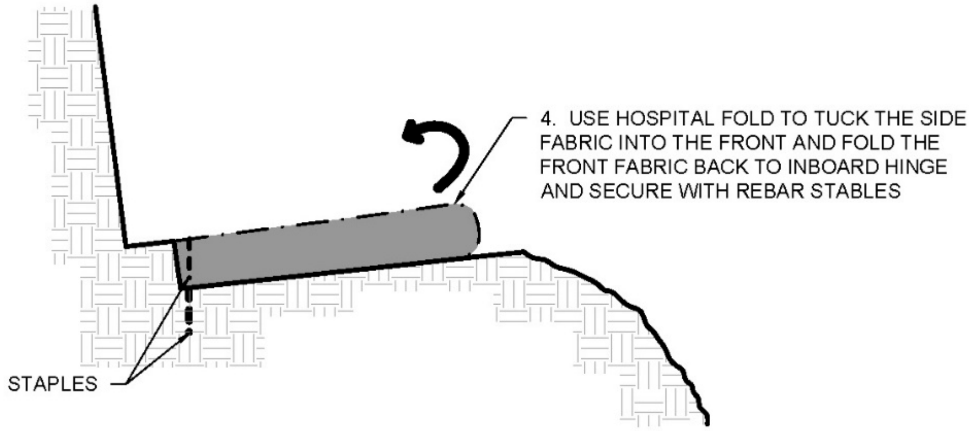
NOT TO SCALE

Rather than having to handle the entire roll, it is easier to unroll what is needed for each tier and cut that length from the roll. In the above example, cut off six 13-foot lengths of fabric. Place one end of these pre-cut lengths of fabric at the inboard hinge of the foundation (the back of the foundation) next to the cut bank, and staple it in place by driving in U shaped pieces of rebar every 4 feet along the inboard hinge of the fabric with a single jack to keep the fabric from moving or being pulled forward. (See Figure 13.28.) Use a utility knife to cut small holes in the fabric to accommodate the staples. The staples are fabricated from 3/8-inch rebar and are approximately 12 inches wide and 18 inches long. Use a rebar bender and cutter to fabricate the staples. When the fabric is unrolled to where the front of the retaining wall will be, it is left there and is filled with a 1-foot deep layer of the B horizon soil from the initial excavation or imported aggregate. (See Figure 13.28.) Use tampers or plate compactors to compact this fill material in 2 to 3 inch lifts as it is placed. The earthen banks at the rear and sides of the foundation will help contain the backfill as it is being compacted. Care must be taken at the front of the wall since that area is open until the fabric is folded back on itself.

Once the layer of backfill is nearly complete, the fabric at the front of the wall is partially pulled back and temporarily pinned to keep the backfill from spilling out. (See Figure 13.28.) Continue placing and compacting backfill until the designed thickness of the tier is achieved. Carefully unpin the fabric at the front of the wall, and then fold the sides of the fabric (the extra 3 feet) back on top of the fill material. (See Figure 13.28.) Using a hospital fold or similar, fold the front of the fabric over the sides and pull the remaining fabric tightly back over the compacted fill to the inboard hinge. It takes a little effort to pull the fabric over the fill while maintaining a well-shaped and even-height tier and a uniform front to the face of the wall. U-shaped rebar staples are used to fasten the fabric along the inboard hinge every 4 feet. (See Figures 13.28 and 13.29.)

The next length of fabric is rolled out toward the front of the wall just as before, but stops short of the previous tier to achieve the prescribed batter determined by the layout calculations. (See Figure 13.29.) Once again, this length of fabric is filled with backfill to a depth of 1 foot. The backfill is compacted and the sides and front are folded, tucked, pulled back, and stapled. If there is insufficient backfill from the foundation excavation to fill all the layers of the wall, more can be imported from construction or maintenance activities along the trail. The process is repeated with succeeding tiers, each “stepped back” the prescribed batter from previous tiers until the final tier is installed and stapled with U-shaped rebar at the back of the wall. (See Figure 13.30.)

END VIEW



END VIEW

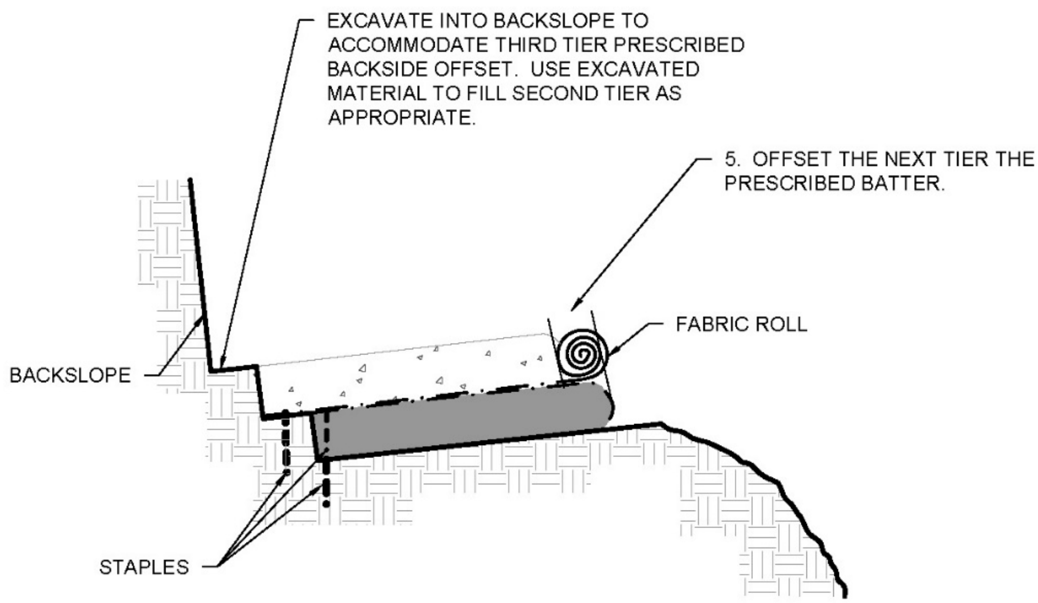


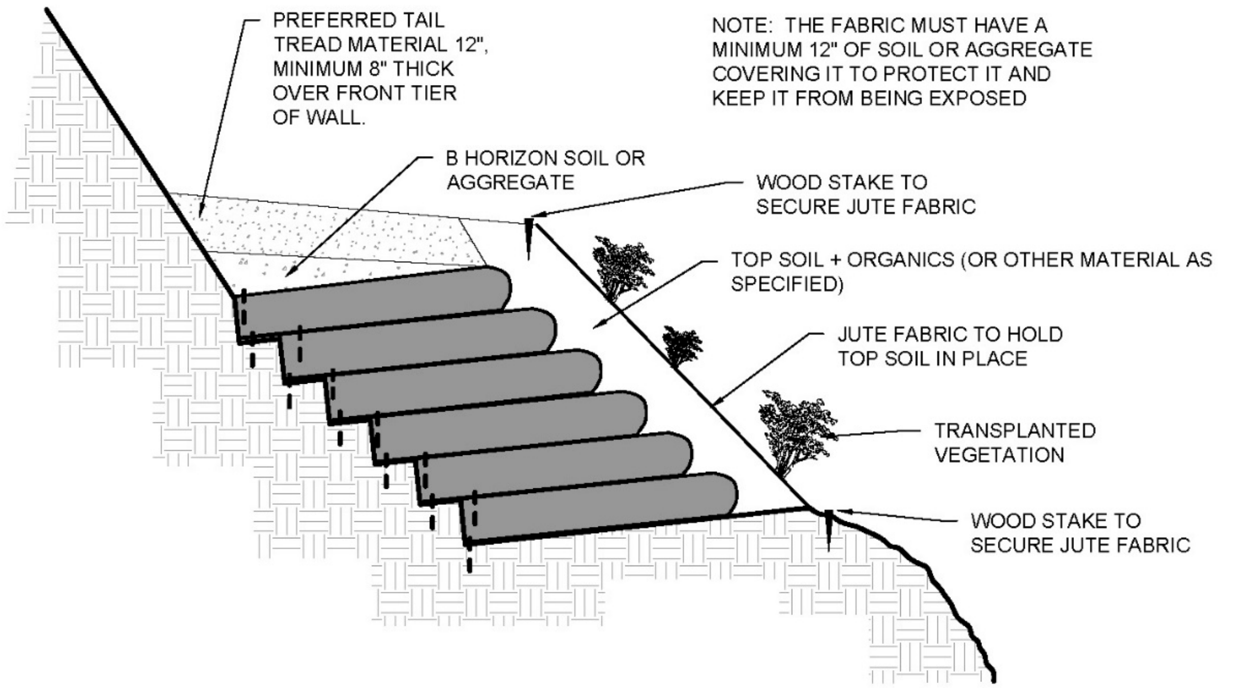
Figure 13.29 - Geotextile Fabric for Encapsulated Soil Walls Continued

GEOTEXTILE FABRIC FOR ENCAPSULATED SOIL WALLS CONTINUED

CALIFORNIA STATE PARKS

NOT TO SCALE

GEOTEXTILE FABRIC WALL WITH 45 DEGREE BATTER (END VIEW)



GEOTEXTILE FABRIC WALL WITH STEEPER CUTBANK (END VIEW)

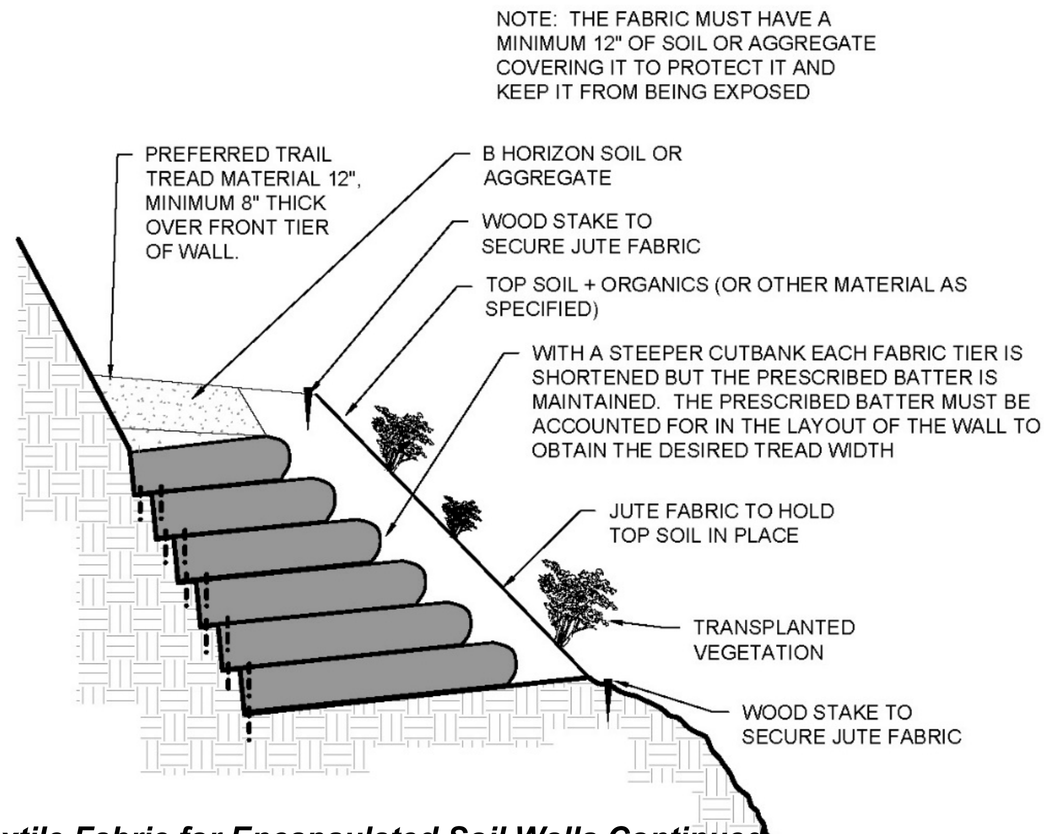


Figure 13.30 - Geotextile Fabric for Encapsulated Soil Walls Continued

GEOTEXTILE FABRIC FOR ENCAPSULATED SOIL WALLS CONTINUED

CALIFORNIA STATE PARKS

NOT TO SCALE

If the cut bank cannot be laid back at an angle of 45 degrees or less, the width of the fabric tiers above the first tier must be shortened to compensate for the steeper cut bank. The layout for this installation must ensure that each tier steps back the prescribed batter to retain the 45-degree or less angle to the wall face and that the top tier is deep enough to provide the designed tread width. (See Figure 13.30.)

Once the geotextile wall is complete, the top of the wall receives approximately 12 inches of backfill suitable for trail tread. The minimum tread depth over the top front of the final wall tier is 8 inches. The tread material does not extend beyond the outside edge of the top tier of the retaining wall. The surface is shaped and compacted to provide the desired drainage, and the front of the wall is covered with topsoil from the excavation. If the excavation yields insufficient topsoil it may need to be imported from another location on the trail.

A minimum depth of 1 foot of soil is placed over the front of the wall. Organics are spread over the soil, and if necessary, a layer of jute netting is laid over the face of the wall to help contain it. Another way to install the netting is to put it down before the soil is placed on the face of the wall. Once the soil is in place, a stiff wire with a hook is used to pull the netting through the soil to the surface to ensure that the netting it is integrated into the soil for the best retention. The surface is lightly tamped with a McLeod and organics are spread over it again. Vegetation salvaged earlier is transplanted in the soil on the face of the wall to promote re-growth. (See Figure 13.30.)

13.16. Cellular Confinement Retaining Walls

13.16.1. Applications

Cellular confinement (also referred to as “geocell”) retaining walls have similar applications as geotextile fabric walls. They stabilize the trail bed and retain fill material below the trail and fill used to bridge over tree roots and rocks. These walls are constructed using open cells made from strips of polyethylene that form a honeycomb structure. Cellular confinement comes in heights from 3 to 8 inches. The 8-inch height is the most efficient to install because it requires less tiers. When filled with backfill or other material, these structures use the weight of earthen material contained within the cells, along with the friction between the layers of cells, to contain and unitize fill material. (See Photo 13.17.)

Photo 13.17 - Cellular Confinement Wall

13.16.2. Attributes

These walls are simple to construct and require minimal skills and tools. Cellular confinement strips are compact and lightweight, and can easily be transported over long distances. They are effective at retaining moderate amounts of fill, stabilizing fill material below the trail, and containing fill to bridge over rocks and tree roots. Only a small workforce is needed to transport and assemble these structures. Unlike geotextile fabric walls, cellular confinement walls can be used in areas where drainage is required. The cellular confinement strips can be purchased with perforations that allow water to pass through the cells. This application is limited to low flow seeps and springs. Like geotextile walls, these structures have only been in use for thirty years, so it is difficult to determine their life span. If not exposed to ultraviolet light, the walls should last for decades. Cellular confinement retaining walls can be designed by a licensed engineer to contain large volumes of material and exceed the height of most of the retaining walls discussed in the chapter.

13.16.3. Limitations

Cellular confinement retaining walls are similar to geotextile fabric walls in their application. Certain land management regulations, such as those applied to wilderness areas, prohibit the use of synthetic materials. The architectural design and aesthetic qualities of these walls may not be appropriate in some locations. If not covered with soil and re-vegetated, these structures are unsightly and will quickly deteriorate from exposure to ultraviolet light. In some locations, vegetation re-growth may be too slow to consider use of this retaining structure. The cost of the material is relatively high but is offset by the ease of construction and the corresponding reduced labor cost.

13.16.4. Construction

There are many manufacturers of cellular confinement material. Cellular confinement material comes in strips of 3 to 8 inches in height, 8 to 10 feet in width, and 13 to 66 feet in length. Individual cells are 4 to 12 inches wide. Most manufacturers will fabricate the strips to specifications within these ranges. Order strips to the length, width, and height required for the project. Individual strips can be stapled together with staple pliers or clips, which can be purchased from most cellular confinement manufacturers or local hardware stores. In terms of strength, the U.S. Army Corps of Engineers recommends a minimum cell seam peel strength of 180 pounds. If a cellular confinement wall is planned where drainage is an issue, it can be purchased with holes pre-drilled through the cells to allow water to pass. Holes can also be drilled once the material is received. Cellular confinement also comes in different colors, however, since the cells should never be exposed in trail applications, color should not be a factor.

Prior to construction, decide on the size of the retaining wall and layout the foundation using the same process previously discussed. Non-engineered cellular confinement walls require a foundation similar to that used for geotextile fabric walls.

It is recommended that a cellular confinement wall have a maximum angle of 45 degrees. This angle is necessary for retaining the soil covering the face of the wall more than it is necessary for stability. Cellular confinement walls can be designed to have a much steeper face, but it is difficult to retain the topsoil and plants needed to cover the wall with steeper designs. If required, an angle steeper than 45 degrees may be achieved if the face of the wall is covered with rock rather than soil. A non-structural rock facing is the most stable at angles steeper than 45 degrees. With this type of rock facing, each rock should have a minimum of three points of contact with adjacent rocks. A shallow footing at the base of the rock facing is required to anchor the bottom rocks and keep them from sliding downslope.

Similar to geotextile retaining walls, the excavation of the foundation is performed with hand tools such as picks, axe (cutter) mattocks, Pulaskis, hazel hoes, and McLeods. Where appropriate and feasible, excavation can be accomplished with a mini excavator. Prior to digging, vegetation suitable for transplanting is salvaged from the work area and kept in wet burlap sacks until it can be planted in the soil on top of the face of the wall. Once excavation begins, all organics and topsoil from the area are saved for later placement on the completed retaining wall. Save all B horizon soils for use as backfill material. When excavating the foundation, the minimum rearward tilt into the hill slope should be 10% to ensure that the weight of the wall is transferred into the hill slope.

Construction begins by laying out the cellular confinement strip on the foundation. The leading edge of the strip should be at the designed front of the wall. Make sure there is sufficient space for the bench that will be required to support the soil that covers the face of the wall when it is complete. Staple or clip one or more strips together to achieve the designed dimensions, as necessary.

Open the strip to its full dimensions. U-shaped rebar called “spreaders” are placed along the length of the strip at intervals necessary to keep the strip fully spread until it is filled with backfill material. The rebar can be fabricated using 3/8-inch rebar and a rebar cutter and bender. (See Figure 13.31.) Rebar should be a minimum of 12 inches high and long enough to match the width of the cellular strips. Metal tendons, clips, and anchor pins can also be used to reinforce the geocells and secure them to the ground.

If the wall needs to drain water, the material placed into the open cells must be porous enough to allow water to pass through without clogging. If not, the cells are filled with B horizon soils saved during excavation of the foundation. (See Figure 13.31.) If there is insufficient soil from the excavation to fill all the layers of the wall, soil can be imported from construction or maintenance activities along the trail.

The cells should be filled from the back of the wall to the front of the wall. Once all the cells have been filled, gaps between the cellular tiers and the hill slope are filled with porous material or B horizon soil, depending on the application. The rebar spreaders are removed and the soil is compacted with tampers. Start the compaction at the rear of the wall and move toward the front. Be careful not to over-compact the material in the cells because it could cause the cells to lift if the backfill material is forced out the bottom of the cells. While compacting the fill material, check the top of the cells with a level to ensure the 10% rearward tilt is maintained. (See Figure 13.31.) The cellular strip for the second tier is laid out similar to the first tier; however, the starting point for the front of the tier is further in toward the hill slope to achieve the prescribed batter. The wall building process is repeated again with succeeding tiers set back to achieve the proper batter until the final tier is installed.

Once the wall is complete, the top of the wall receives approximately 12 inches of backfill suitable for trail tread. The minimum tread depth over the top front of the final wall tier is 8 inches. The surface is shaped and compacted to provide the desired drainage, and the front of the wall is covered with topsoil from the excavation. A minimum of 1 foot of soil is placed over the front of the wall. Organics are spread over the soil, and if necessary, a layer of jute netting is laid over the face of the wall to help contain it. Another way to install the netting is to put it down before the soil is placed on the face of the wall. Once the soil is down, a stiff wire with a hook is used to pull the netting through the soil to the surface. This method ensures that the netting comes to the surface sporadically so it is integrated and can better hold the soil. The surface is lightly tamped with a McLeod and organics are spread. Vegetation salvaged earlier is transplanted in the soil to promote the re-growth of the face of the wall. (See Photo 13.18 and Figure 13.31.)

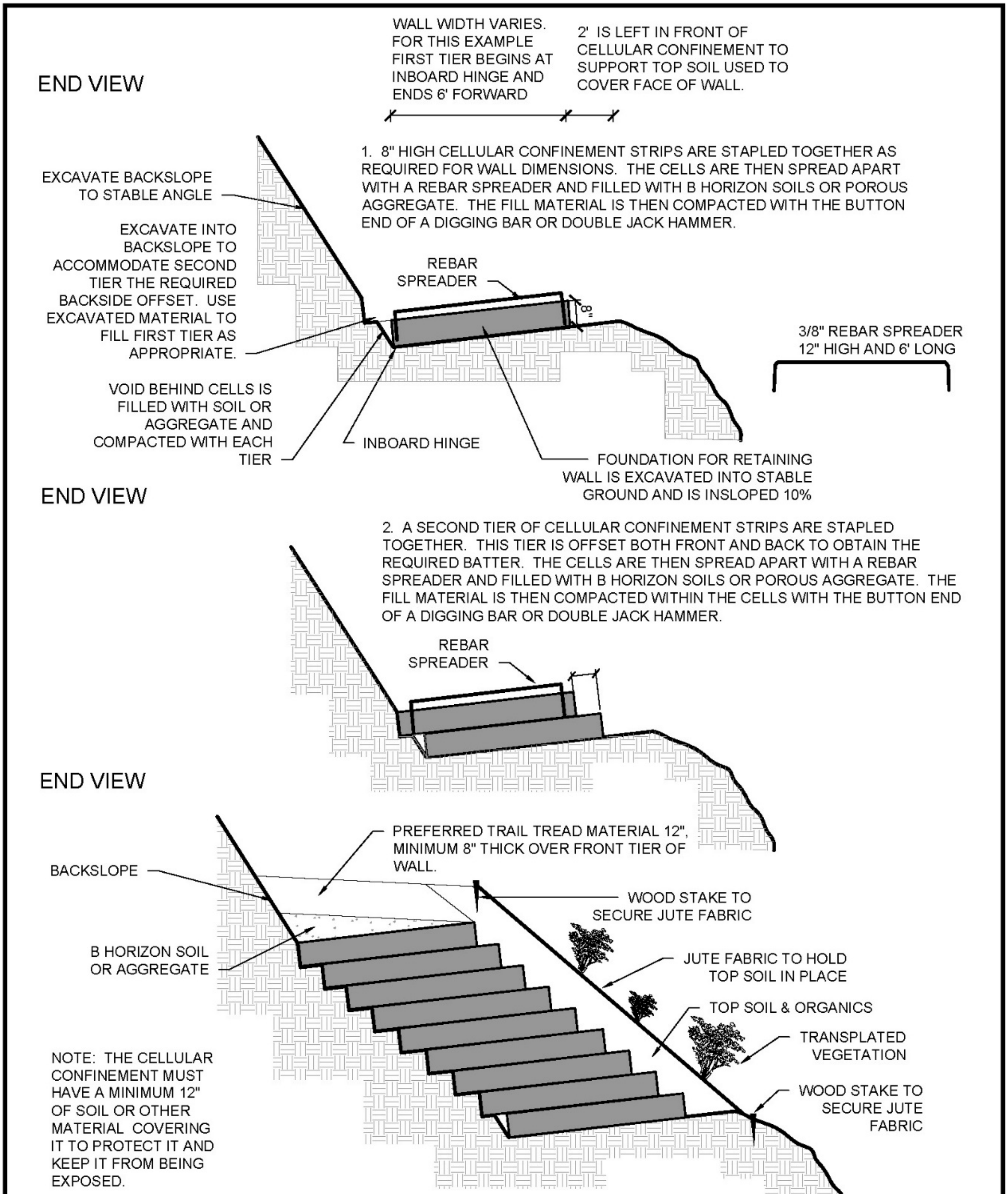


Figure 13.31 - Cellular Confinement Retaining Walls

CELLULAR CONFINEMENT RETAINING WALLS

CALIFORNIA STATE PARKS

NOT TO SCALE

Photo 13.18 - Cellular Confinement Wall Revegetated

13.17. Gabion Basket Retaining Walls

13.17.1. <u>Applications</u>

A gabion basket retaining wall can be used for stabilizing the trail bed and retain fill material below the trail or can serve as an abutment, mid-span support, or ramp for bridges. (See Photo 13.19.) It is constructed in tiers and made of wire baskets and wire ties, filled with rock, and held together by gravity and friction.

Photo 13.19 - Gabion Walls Prior to Completion of Rock Covering

13.17.2. Attributes

These walls are simple to assemble and can buttress unstable slopes, be used for free standing structures such as bridge abutments or mid-span supports, and can contain moderate amounts of fill. If native materials are available from the clearing and construction phases of the project or can be quarried close to the site, this structure is comparatively inexpensive. When properly used, gabion walls can last decades.

13.17.3. Limitations

The biggest drawback to a gabion wall is its low aesthetic value. Unless covered with native soil and vegetation, the wall is unsightly in a natural setting. This structure is often mis-used for streambank stabilization, where it is vulnerable to abrasion from rocks transported through the watercourse. Rocks carried during high flow events can quickly wear through the wire mesh and destabilize the entire structure. Obtaining the appropriate rock to fill the basket may also be a problem, because the rock is usually imported. Most gabion basket walls are located on Class I trails or near trailheads.

13.17.4. Logistics

The rock used to fill a gabion basket is usually purchased from a local quarry and transported to the worksite. Rock can also be generated from trail clearing and excavation or gathered from rock outcroppings or talus slopes close to the site. Imported rock can be trucked to the trailhead from a commercial quarry, but transportation from the trailhead to the site can be difficult, time consuming, and expensive if the worksite is distant. The methods used to transport the rock are similar to those discussed in dry stone masonry.

13.17.5. Construction

A gabion is a wire mesh box or mattress-shaped basket filled on-site with hard, durable rock. Square or rectangular panels that make up a single gabion can be fabricated from either welded or twisted wire mesh. Gabions (square or rectangular) are fabricated from standard or custom designed wire of various widths, depths, and lengths.

Gabion panels are joined to form a single unit. The minimum required tensile strength of the wire should be 60,000 pounds per square inch and the minimum galvanizing is 0.80 ounce per square foot.

Most gabion panels (twisted mesh or welded mesh) are manufactured from 11- or 9-gauge wires, depending on the application. Tie wires should be galvanized and no smaller than 13.5 gauge. Alternatively, galvanized spiral binders of the same gauge as the panels are used, with a 3-inch separation between loops.

Individual units are divided into cells of equal length, none greater than 3 feet, with diaphragms made of the same construction as the main panels. Wire mesh panels (base, ends, sides, diaphragms, and lid) are assembled so that the strength and flexibility at connections is equal to a single panel.

Prior to construction, determine the size of the retaining wall and the layout of the foundation. Gabion basket retaining walls require a wide foundation. The width of the footing must be equal to one and a third times the height of the wall. In addition, there must be a bench in front of the wall that is wide enough to support the soil that will cover the face of the structure. This additional bench width should be approximately a third of the wall height and no less than 30 inches deep. The face of a gabion basket wall should have a maximum batter of 45 degrees. This angle is necessary for retaining the soil covering the face of the wall more than it is necessary for stability. Gabion basket walls can be designed to have a much steeper face, but it is difficult to retain the topsoil and plants needed to cover the wall with steeper designs. If required, an angle steeper than 45 degrees may be achieved if the face of the wall is covered with rock rather than soil. A non-structural rock facing is the most stable at angles steeper than 45 degrees. With this type of rock facing, each rock should have a minimum of three points of contact with adjacent rocks. A shallow footing at the base of the rock facing is required to anchor the bottom rocks and keep them from sliding downslope. The lift for each tier should not exceed 3 feet.

In most trail applications, excavation of the foundation is performed with hand tools such as picks, axe (cutter) mattocks, Pulaskis, hazel hoes, and McLeods. Since these structures are more likely to be constructed at or near a trailhead, excavation can be accomplished with a mini excavator. Prior to digging, vegetation suitable for transplanting is salvaged from the work area and kept in wet burlap sacks until it can be planted in the soil on top of the face of the wall. Once excavation begins, all organics and topsoil from the area are saved for later placement on the completed retaining wall. Save all B horizon soils for later use as backfill material. When excavating the foundation, the minimum rearward tilt into the hill slope is 10% to ensure that the weight of the wall is transferred into the hill slope.

Each style of gabion is assembled by the following method:

Rotate the panels into position and join the vertical edges. Welded wire panels are tied or joined along all vertical edges with spiral binders. (See Figure 13.32.) When tied, the tie wire passes through each mesh opening along the joint and is secured with a locked loop. Twisted wire panels are joined along the vertical edges with tie wire or spiral binders. When the panels are joined with tie wire, use 4-inch nominal spacing, and alternate single and double-locked loops. The end of each binder is crimped to secure the spiral in place. There should not be any openings greater than 4.75 inches (line dimension) along the edges or at the corners of tied or spiral bound gabions of either mesh style. Insert wire stiffeners (4 per exposed face) into the baskets to maintain their shape and keep them from deforming when filled with rock. (See Figure 13.32.)

The empty gabions are set in place and each is connected to the adjacent gabion with tie wire along the top and vertical edges. Tie each layer to the underlying layer along the front, back, and sides. The tying is done in the same manner as for assembling the baskets.

Before filling each gabion with rock, remove all kinks and folds in the wire fabric and properly align the baskets. Rock for filling the gabions should vary in size and conform to the following graduation:

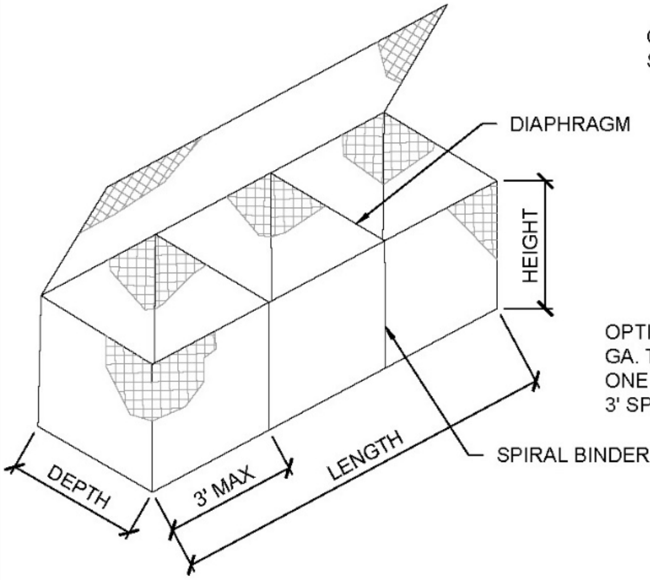
Borrow Pit Screen Size (inches)	**Percent Passing**
10	100
8	95-100
4	0-5

Carefully place the rock into the gabions to ensure proper alignment, avoid bulges, and provide a minimum of gaps. All exposed rock surfaces should have a smooth and neat appearance, with no sharp edges projecting through the wire mesh.

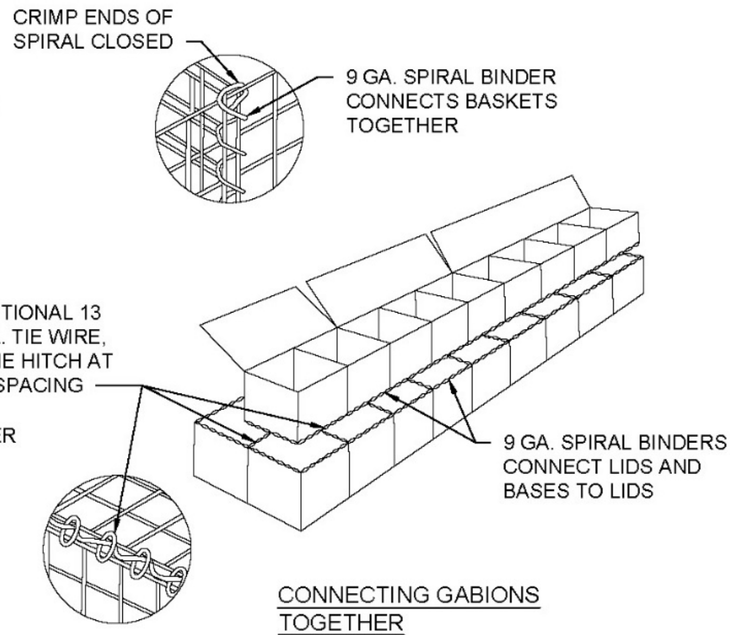
The rock is placed in lifts to allow installation of internal connecting wire. Internal connecting wire is used to maintain a relatively flat, smooth external surface for the 3-foot high baskets. Internal connecting wires are galvanized, at least 13.5 gauge, and fastened at the vertical 1/3 points as shown. (See Figure 13.32.)

The top layer of rocks fills the gabion so that the lid will lie on the rock when it is secured. The lid is secured to the sides, ends, and diaphragms with the wire in the same manner as for joining the vertical edges.

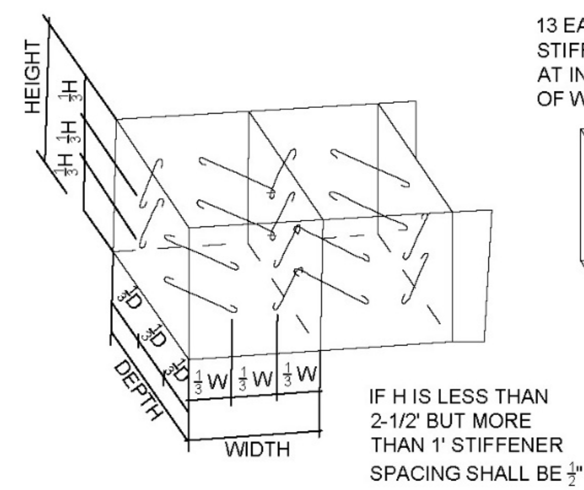
Once the gabion basket wall is complete, the top receives a minimum of 1 foot of soil suitable for trail tread. The surface is shaped and compacted to provide the desired drainage, and the front of the wall is covered with topsoil from the initial excavation. A minimum of 1 foot of soil is placed over the front of the wall. Organics are spread over the topsoil, and if necessary, a layer of jute netting is laid over the face of the wall to help contain it. Another way to install the netting is to put it down before the soil is placed on the face of the wall. Once the soil is down, a stiff wire with a hook is used to pull the netting through the soil to the surface. This method ensures that the netting comes to the surface sporadically so it is integrated and can better hold the soil. The surface is lightly tamped with a McLeod and organics are spread. Vegetation salvaged earlier is transplanted to the soil covering the front of the baskets to promote the re-growth and naturalization of the face of the wall. (See Figure 13.33.)



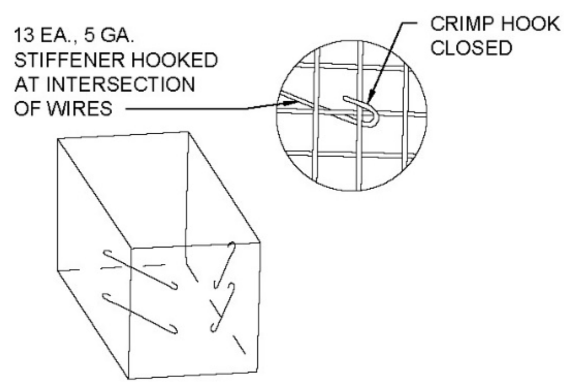
TYPICAL ASSEMBLED GABION



CONNECTING GABIONS
TOGETHER



END GABIONS



INTERIOR GABIONS

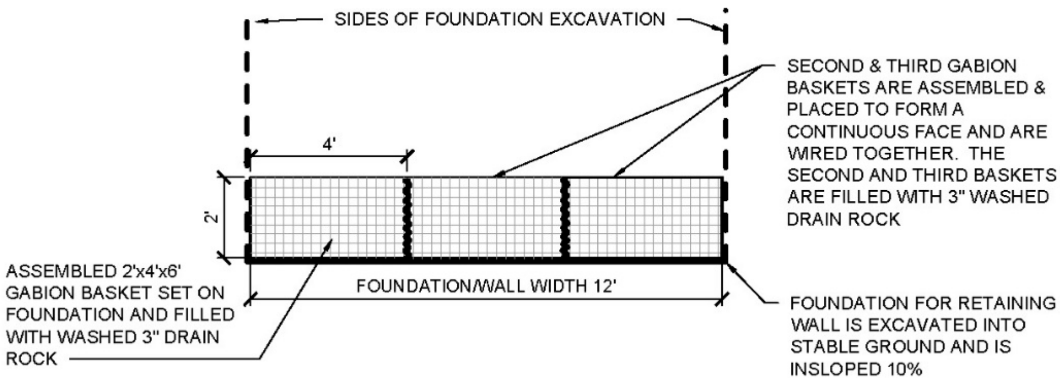
Figure 13.32 - Gabion Basket Retaining Walls

GABION BASKET RETAINING WALLS

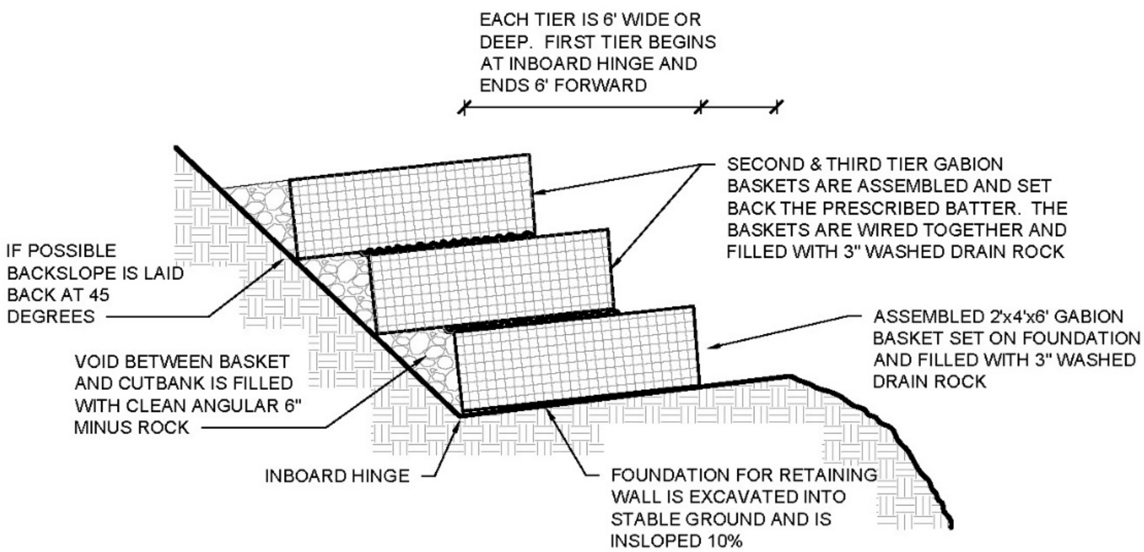
CALIFORNIA STATE PARKS

NOT TO SCALE

GABION BASKET RETAINING WALL (FRONT VIEW)



GABION BASKET RETAINING WALL (END VIEW)



COMPLETED GABION BASKET RETAINING WALL (END VIEW)

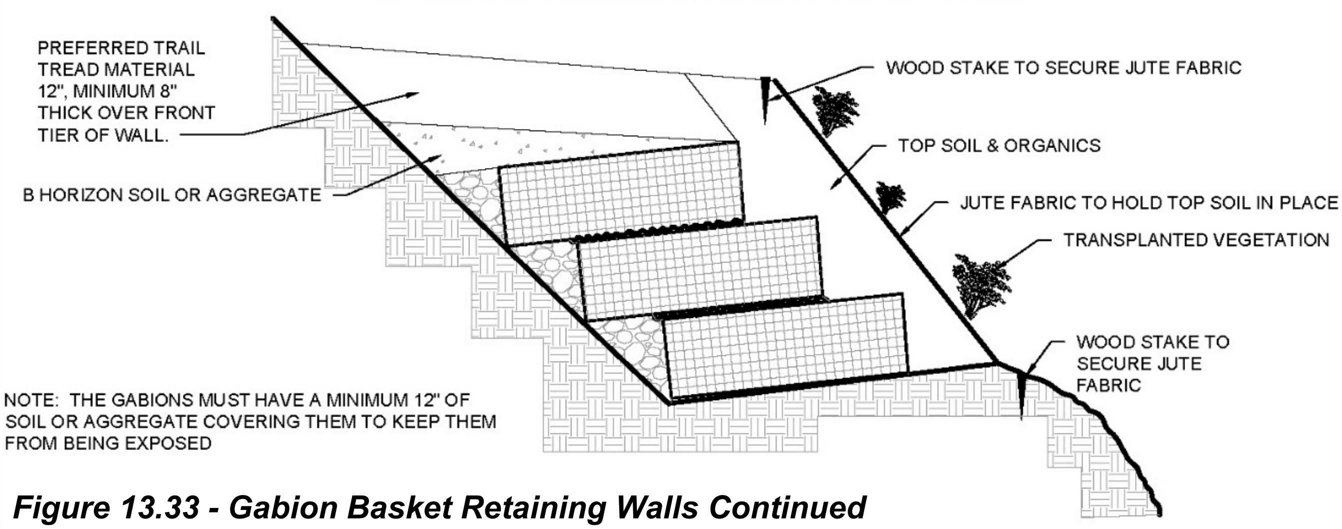


Figure 13.33 - Gabion Basket Retaining Walls Continued

GABION BASKET RETAINING WALLS CONTINUED

CALIFORNIA STATE PARKS

NOT TO SCALE