5-12 EARTH RETAINING SYSTEMS USING GROUND ANCHORS

(I) General Information

Common applications of earth retaining systems using ground anchors include soldier pile walls with anchors, sheet pile walls with anchors, diaphragm walls with anchors, and secant pile walls with anchors. Typical construction proceeds in a top-down fashion. Ground anchors are also often used to stabilize landsides.

This memo describes areas that are typical in design of earth retaining systems using ground anchors. For more detailed information, please see the references listed at the end of this memo.

(II) Lateral Earth Pressures

Consult with Geotechnical Services for suitable lateral earth pressure distribution for the project. For earth retaining systems constructed from the top down and restrained by ground anchors (tiebacks), the lateral earth pressure acting on the wall height, H, may be determined as described below.

The lateral earth pressure distribution for the design of temporary or permanent anchored walls constructed in cohesionless soils may be determined using equations provided in AASHTO LRFD BDS (2007). In those special situations where there exists external loading in addition to lateral earth pressure, such as a slip plane or adjacent structures, etc, the following equations based on P_{total} may be used to determine p_a. Consult Geotechnical Services for the evaluation of P_{total} in these cases.
For walls with a single level of anchors:

$$P_a = \frac{P_{total}}{0.67H} \tag{5-12.1}$$

For walls with multiple levels of anchors:

$$p_a = \frac{P_{total}}{H - \frac{1}{3}H_1 - \frac{1}{3}H_{n+1}} \tag{5-12.2}$$

where:

p_a = maximum ordinate of pressure diagram (ksf)

P_{total} = total load required to be applied to the wall face with a load factor equal to 1.35 or 1.50 for the retained soil mass when stability is analyzed using an appropriate limiting equilibrium method of analysis, except that P_{total}, per unit length, shall not be less than 1.44 P_a (ksf).

P_a = active lateral earth pressure resultant acting on the wall height, H, and determined using Coulomb's theory with a wall friction angle, δ, equal to zero (ksf).

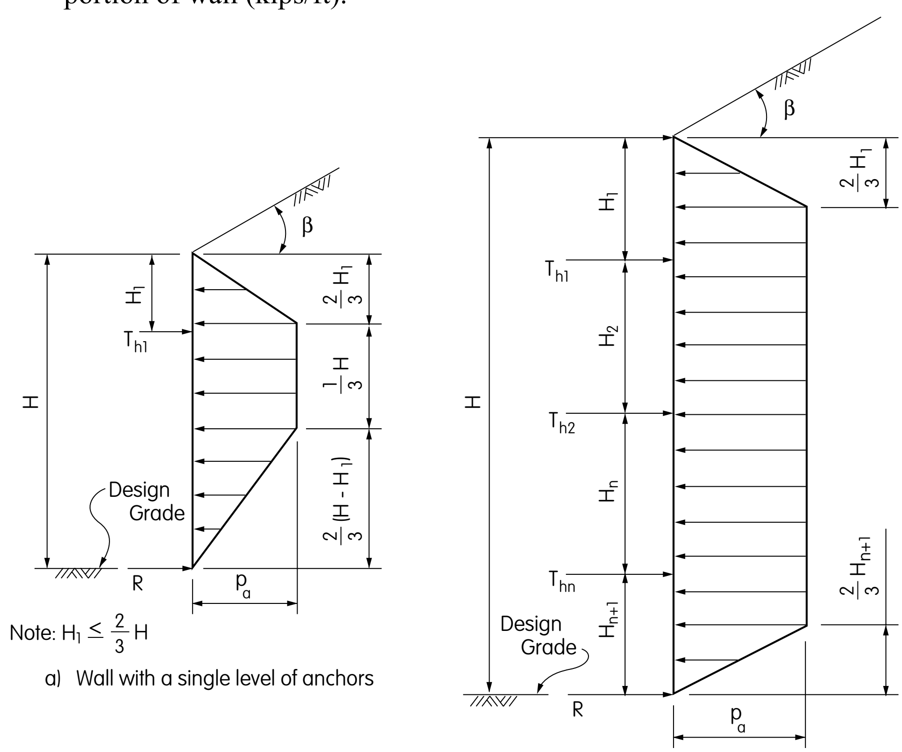
H = wall design height (ft)

H_1 = distance from ground surface at top of wall to uppermost level of anchors (ft).

H_{n+1} = distance from design grade at bottom of a wall to lowermost level of anchors (ft).

T_{hi} = horizontal component of factored design load FDL in anchor at level i (kip/ft).

R = design reaction force at design grade at bottom of wall to be resisted by embedded portion of wall (kips/ft).



a) Wall with a single level of anchors

b) Wall with multiple levels of anchors

Figure 5-12.1

(III) Wall Design

Typical design steps for retaining walls with ground anchors are as follows:

Step 1 Establish project requirements including all geometry, external loading conditions (temporary and/ or permanent, seismic, etc.), performance criteria, and construction constraints. Consult with Geotechnical Services for the requirements.

Step 2 Evaluate site subsurface conditions and relevant properties of the in situ soil or rock; and any specifications controlled fill materials including all materials strength parameters, ground water levels, etc. This step is to be performed by Geotechnical Services.

Step 3 Evaluate material engineering properties, establish design load and resistance factors, and select level of corrosion protection. Consult with Geotechnical Services for soil and rock engineering properties and design issues.

Step 4 Consult with Geotechnical Services to select the lateral earth pressure distribution acting on back of wall for final wall height. Add appropriate water, surcharge, and seismic pressures to evaluate total lateral pressure. Check stability at intermediate steps during contruction. Geotechnical numerical analysis may be required to simulate staged construction. Consult Geotechnical Services for the task, should it be required.

Step 5 Space the anchors vertically and horizontally based upon wall type and wall height. Calculate individual anchor loads. Revise anchor spacing and geometry if necessary.

Step 6 Determine required anchor inclination and horizontal angle based on right-of-way limitations, location of appropriate anchoring strata, and location of underground structures.

Step 7 Resolve each horizontal anchor load into a vertical force component and a force along the anchor.

Step 8 Structure Design checks the internal stability and Geotechnical Services checks the external stability of anchored system. Revise ground anchor geometry if necessary.

Step 9 When adjacent structures are sensitive to movements Structure Design and Geotechical Services shall jointly decide the appropriate level and method of analysis required. Revise design if necessary. For the estimate of lateral wall movements and ground surface settlements, geotechnical numerical analysis is most likely required. Consult with Geotechnical Services for the task, should it be required.

Step 10 Structure Design analyzes lateral capacity of pile section below excavation sub-grade. Geotechnical Services analyzes vertical capacity. Revise pile section if necessary.

Step 11 Design connection details, concrete facing, lagging, walers, drainage systems, etc. Consult with Geotechnical Services for the design of additional drainage needs.

Step 12 Design the wall facing architectural treatment as required by the Architect.

1. Anchored Walls with Soldier Piles

Retaining walls with ground anchors shall be dimensioned to ensure that the total lateral load, P_{total}, plus any additional horizontal loads, are resisted by the horizontal component of the anchor Factored Design Load T_{hi}, of all the anchors and the reaction, R, at or below the bottom of the wall. The embedded vertical elements shall ensure stability and sufficient passive resistance against translation. The calculated embedment length shall be the greater of that calculated by the Designer or Geotechnical Services.

In determining the stability of the embedded vertical elements, only the passive resistance below the critical failure surface or point, O, in Figures 5-12.2 through 5-12.6 whichever is lowest, shall be considered in determining the reaction, R. The active lateral earth pressure below the critical failure surface or point, O, in Figures 5-12.2 through 5-12.6 whichever is lowest, shall also be considered.

When the critical failure surface of the limiting equilibrium analysis associated with the determination of P_{total}, as described in (II) Lateral Earth Pressures, passes a significant distance below the design grade at the bottom of the wall, the anchors should be designed to resist the total load, P_{total}, and the vertical elements of the wall should be designed as a cantilever from the lowest anchor level to the bottom of the wall.

(A) Single Level of Anchors

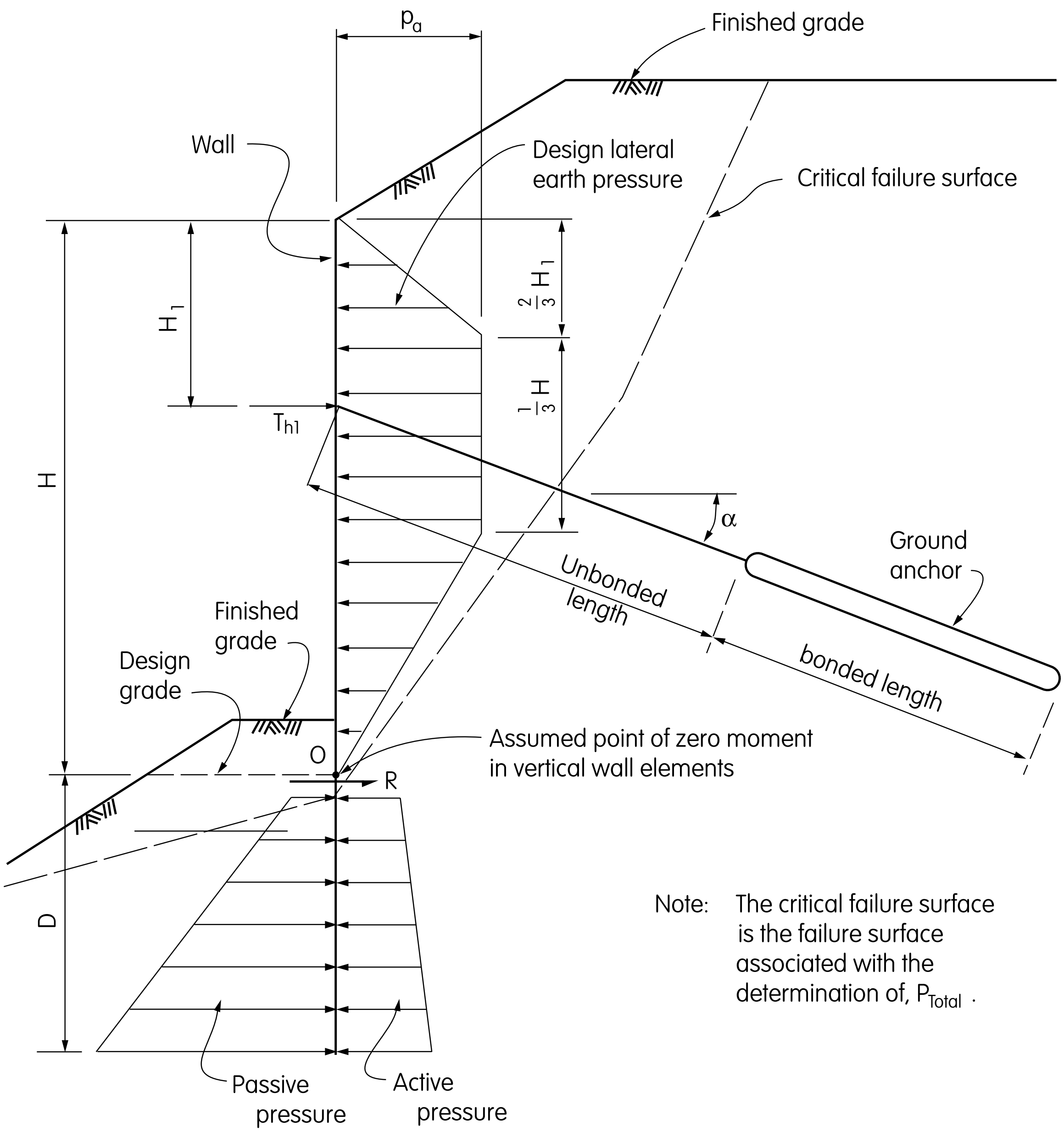


Figure 5-12.2 Anchored Wall with Single Level of Ground Anchors, Critical Failure Surface Near Bottom of Wall, $H_1 \leq = {}^1/_2\ H$

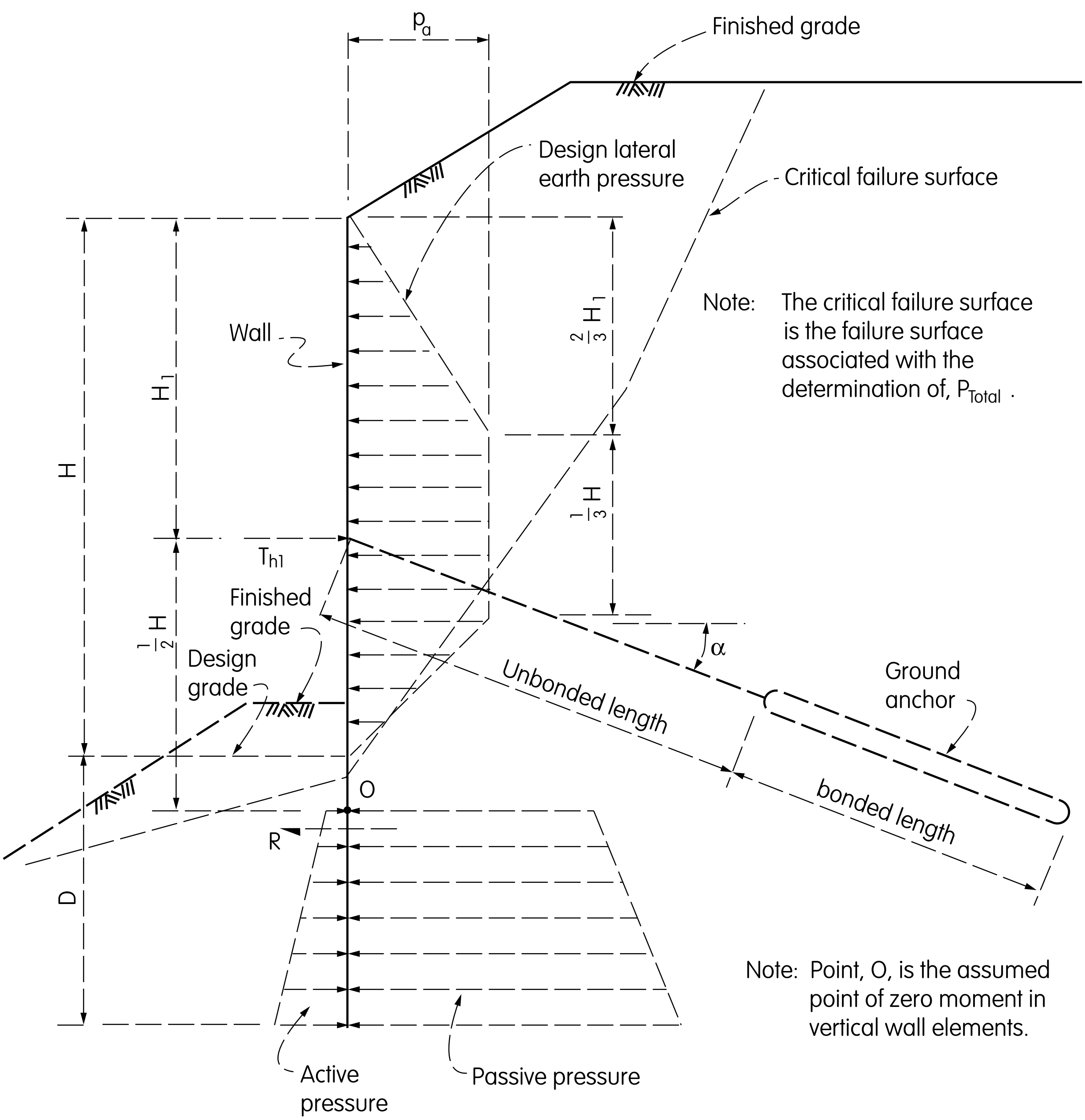


Figure 5-12.3 Anchored Wall with Single Level of Ground Anchors, Critical Failure Surface near Bottom of Wall, $^1/_2 H < H_1 < {}^2/_3 H$

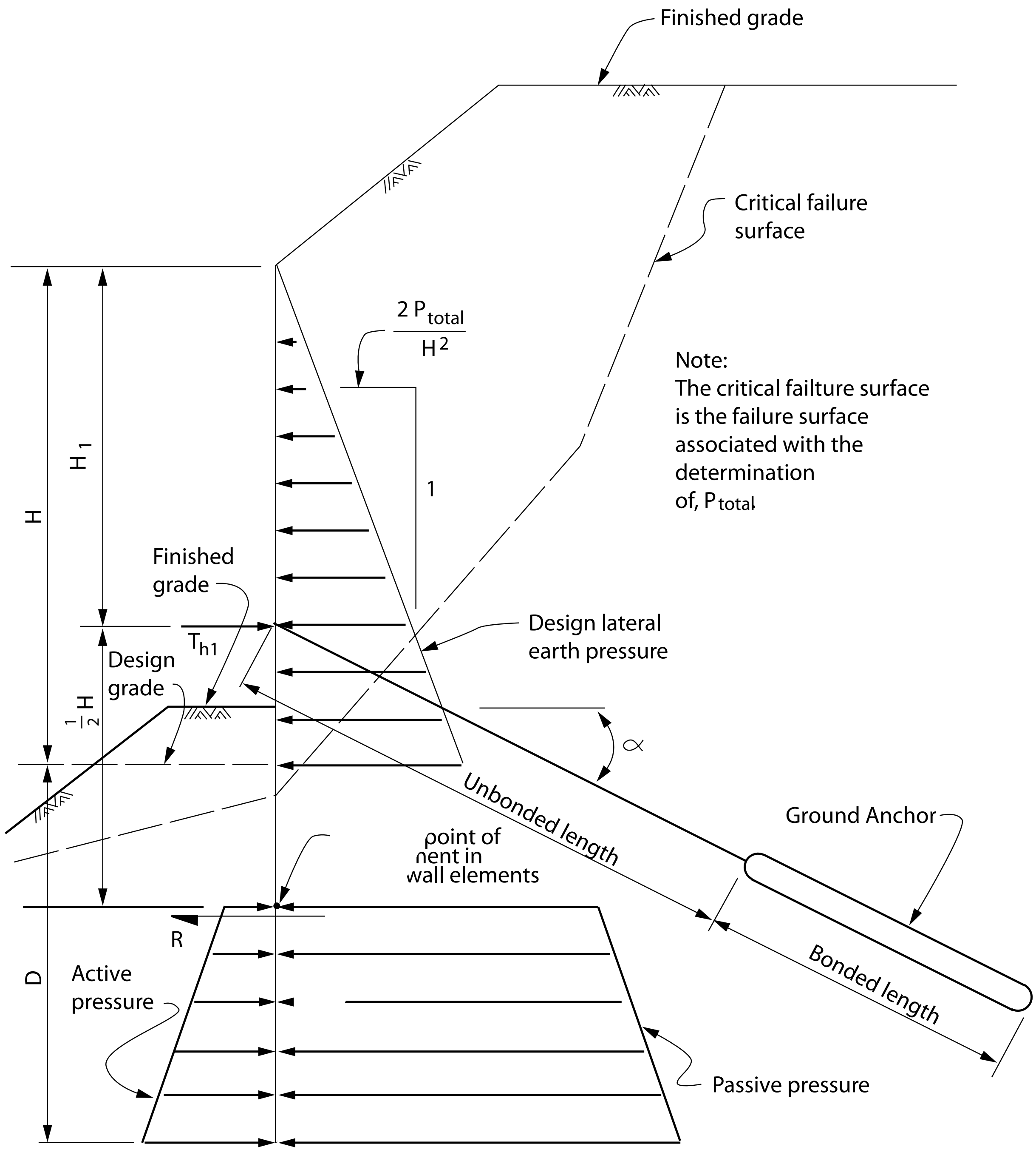


Figure 5-12.4 Anchored Wall with Single Level of Ground Anchors, Critical Failure Surface near Bottom of Wall, $H_1 > {}^2/_3H$

(B) Multiple Levels of Anchors

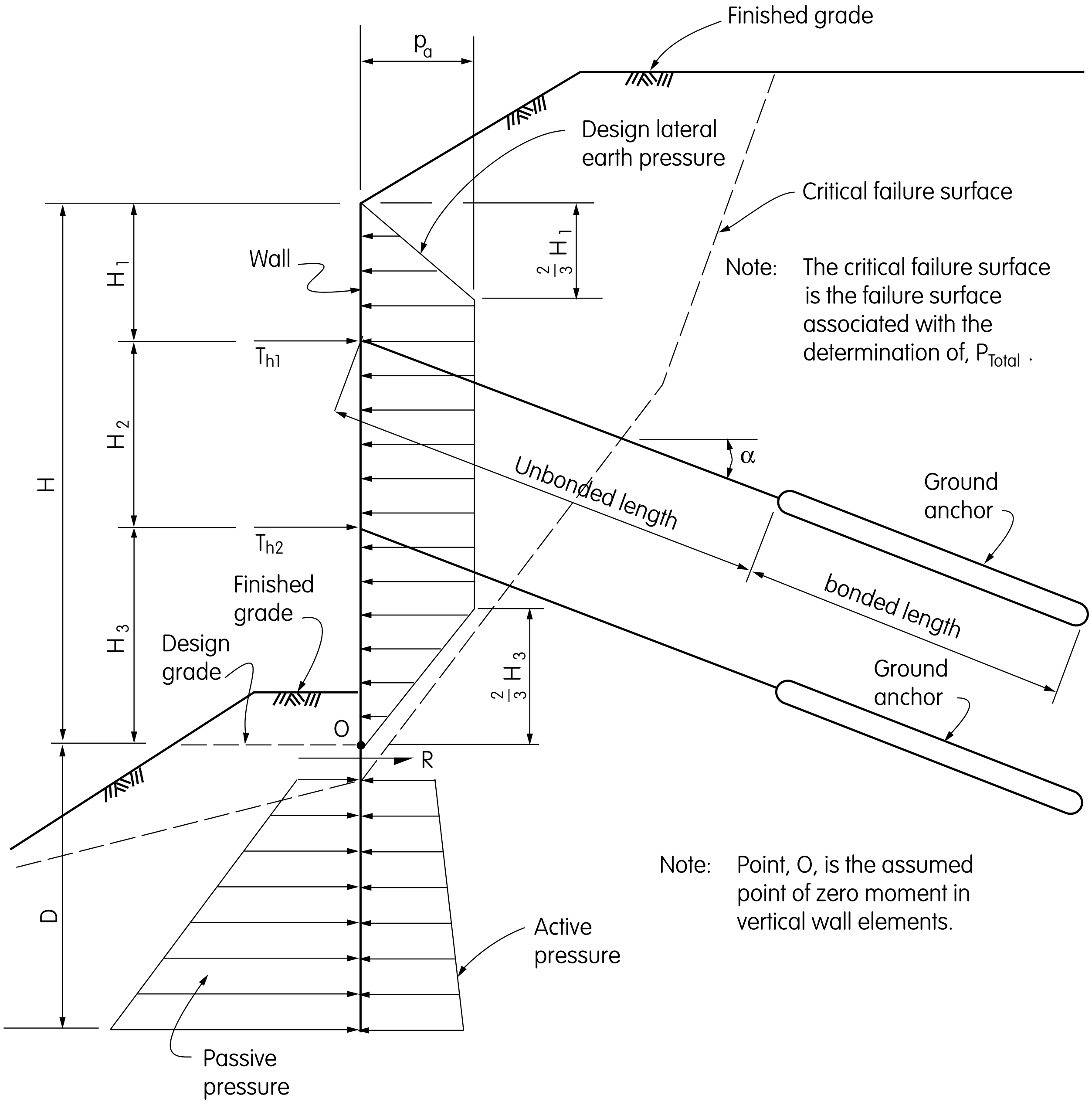


Figure 5-12.5 Anchored Wall with Multiple Levels of Ground Anchors and Critical Failure Surfaces Near Bottom of Wall

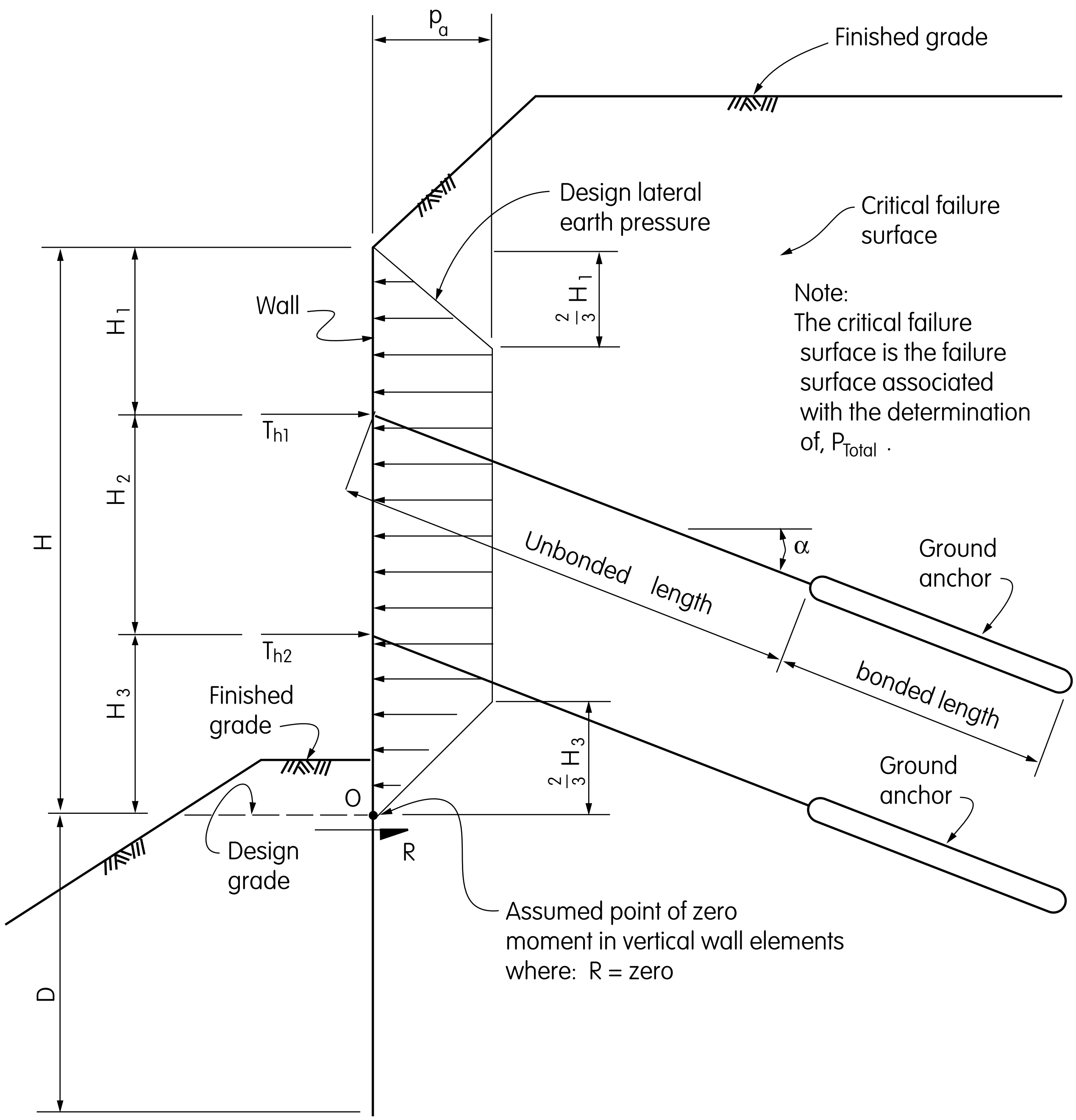


Figure 5-12.6 Anchored Wall with Multiple Levels of Ground Anchors and Critical Failure Surface a Significant Distance below the Bottom of Wall

For the design of walls with a single level of ground anchors, refer to Figures 5-12.2 through 5-12.4 and for walls with multiple levels of ground anchors refer to Figures 5-12.5 and 5-12.6. Use the following design procedure.

1. Consult with Geotechnical Services to determine the design lateral earth pressure and any additional horizontal loading acting on the wall over the design height, H;

2. Consult with Geotechnical Services to determine the passive and active lateral earth pressure acting on the embedded vertical wall elements below the point, O, or the critical failure surface, whichever is lower;

3. Determine the horizontal component of ground anchors Factored Design Load T_{hi}, and reaction, R, that provides equilibrium of horizontal forces above point, O.

    a) For walls with a single level of anchors, take moments about point O to determine T_{h1}, where for walls with H_1 less than or equal to $H/2$, point O is located at the bottom of wall (design grade). For walls with H_1 greater than $H/2$, point O is located $H/2$ below the level of the ground anchors.

    b) For walls with multiple levels of ground anchors, there are a number of suitable methods for the determination of T_{hi} at each level that are in common use. Sabatini, et. al. (1999) provides two methods: 1) the Hinge Method, as shown in Figure 5-12.7, and 2) the Tributary Area Method, as shown in Figure 5-12.8.

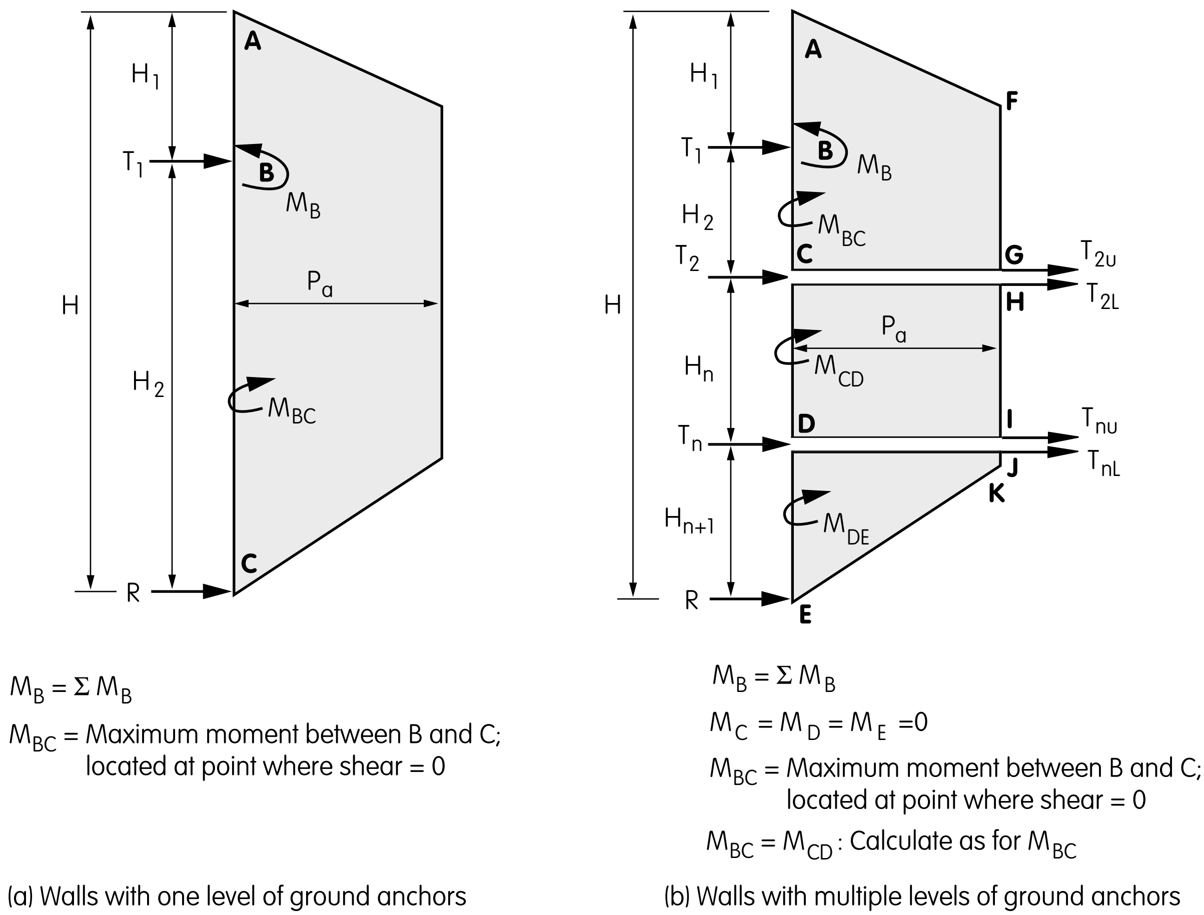
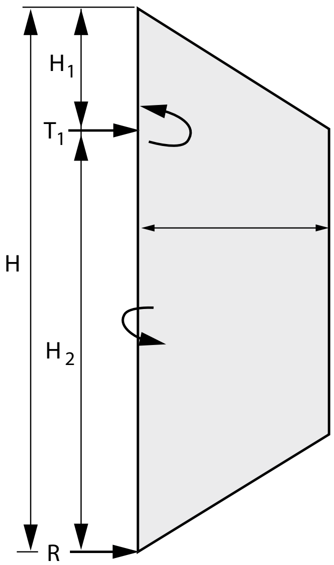


Figure 5-12.7 Calculation of Anchor Loads Using the Hinge Method (After Figure 38, Sabatini, et al, 1999)



$$M_B = \frac{13}{54} H_1^2 p_a$$

$$T_1 = \frac{(23H^2 - 10 HH_1)}{54 (H - H_1)} p_a$$

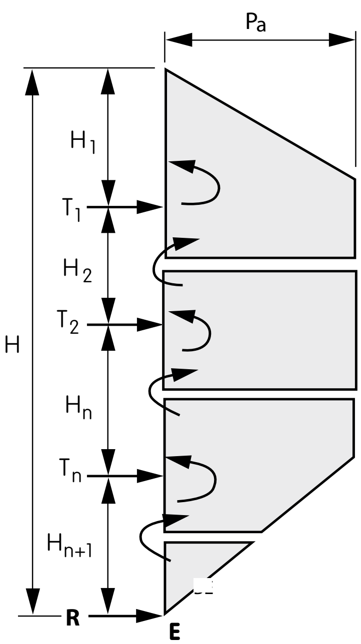
$$R = \frac{2}{3} H p - T_1$$

Solve for point of zero shear

$$x = \frac{1}{9} \sqrt{(26H^2 - 52 HH_1)}$$

$$M_{BC} = Rx - \frac{p_a x^3}{4 (H - H_1)}$$

(a) Walls with single level of ground anchors



$$M_B = \frac{13}{54} H_1^2 p_a$$

$$T_1 = \left(\frac{2}{3} H_1 + \frac{H_2}{2}\right) p_a$$

$$T_2 = \left(\frac{H_2}{2} + \frac{H_n}{2}\right) p_a$$

$$T_n = \left(\frac{H_n}{2} + \frac{23H_{n+1}}{48}\right) p_a$$

$$R = \left(\frac{3}{16} H_{n+1}\right) p_a$$

Maximum moment between B = $pL^2/10$
where L is the larger of H_2, H_n, H_{n+1}

(b) Walls with multiple level of ground anchors

Figure 5-12.8 Calculation of Anchor Loads for Multi-Level Wall Using the Tributary Area Method (After Figure 39, Sabatini, et al, 1999)

4. Determine the factored design load, *FDL*, for the anchors at each level, where, $FDL = T_h/\cos\alpha$, and α equals the inclination from horizontal of the anchors;

5. Determine the embedment, *D*, of the vertical wall elements required to ensure stability against passive failure;

6. Determine the embedment, *D*, of the vertical wall elements required to resist all vertical components of loads. Only the portion of the vertical wall elements below the critical failure surface should be considered in determining the resistance to vertical loads;

7. Use the greater of the two values for embedment, *D*, determined in steps 5 and 6 above;

8. Design the vertical wall elements for all horizontal and vertical loads. Horizontal supports may be assumed at each level of anchors and at point, O;

9. Design the ground anchors.

2. Ground Anchored Diaphragm Walls

Often times, roadway widening projects require partial removal of the embankment slope in front of the existing bridge abutment. Restrained by the existing overcrossing or undercrossing, most of the time there is not enough clearance below the soffit for pile installation; therefore, the regular type of drilled shafts can not be used for the earth retaining structures. Also depending upon the geometry of the existing abutments associated with the proposed earth retaining structures, a top down construction method will be necessary to minimize damage and movement of the existing abutments. A shotcrete layer with ground anchors, followed by a final concrete facing becomes the most appropriate structure type for this application. This type of walls is called a ground anchored diaphragm wall.

There are two considerations for the use of this type of structure:

(A) The Construction Sequence

(i) Excavation: Per OSHA, by lifts of 5 feet maximum per cut, unless another excavation depth is recommended or approved by geotechnical designers;

(ii) Shotcrete: Reinforced shotcrete with cast-in-formed holes for ground anchors;

(iii) Ground Anchors: drill through the formed holes and install tendons/anchors;

(iv) Stressing Ground Anchors: Testing the anchors (at 1.0 *FDL* or greater) and locking off (at 0.67*FDL*).

(v) Proceed down to next level; repeat steps (i) through (iv).

(vi) After all anchors have been stressed a permanent reinforced concrete fascia may also be placed in front of the shotcrete layer

The contractor may choose to reverse the order of (ii) and (iii). If the contractor chooses to keep the cut open for the drilling of ground anchors, the risk will be fully upon the contractor in case there is any embankment sloughing and unstable conditions occur at the bridge abutments.

(B) The Design Approach

Additional lateral pressures induced by the surcharge of spread footing or the lateral loads of the pile footing from the existing bridge abutments shall be included in the design of the earth retaining structure. The following are typical scenarios:

Case (a) End Diaphragm Abutment on Piles with no hinge in the superstructure and skew < 10 degrees

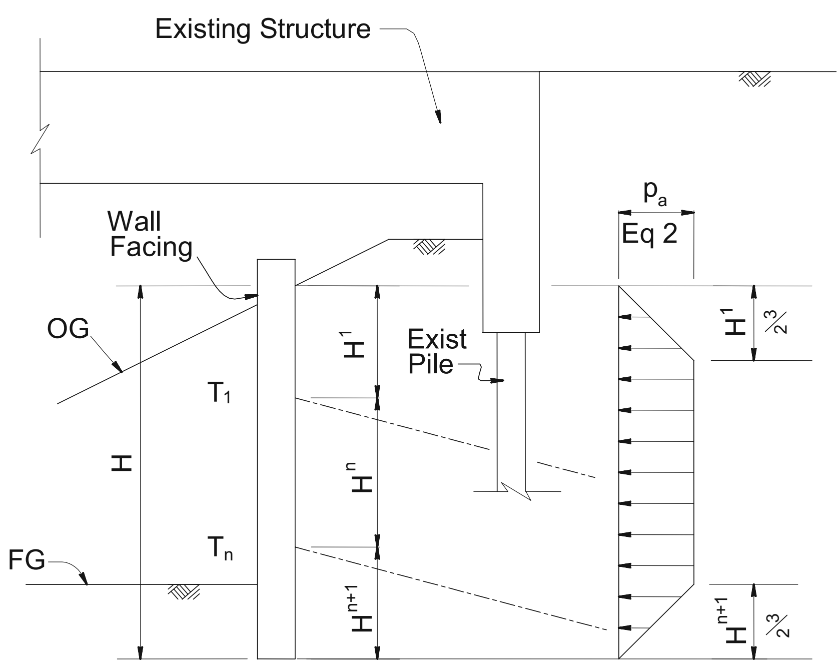


Figure 5-12.9

Assume that the lateral earth pressure on one abutment is resisted by the other abutment. The trial wedge analysis with Coulomb's theory should be used to determine P_{total}.

Case (b) End Diaphragm Abutment on Piles with hinges in the superstructure and/or skew > 10 degrees

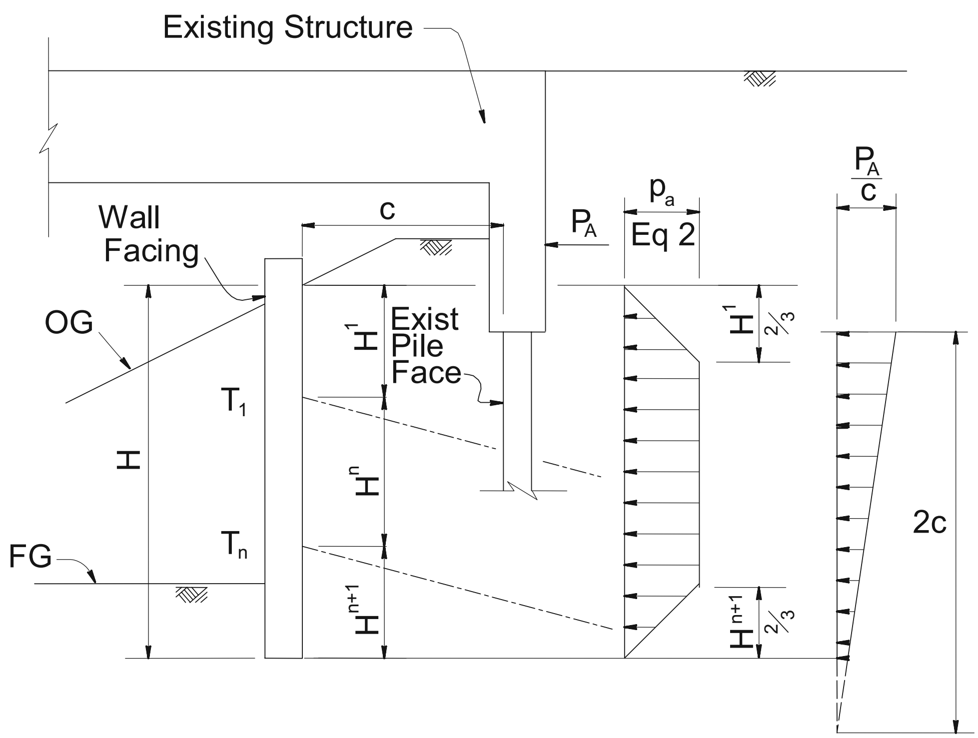


Figure 5-12.10

The trial wedge analysis with Coulomb's theory should be used to determine P_{total}.

Case (c) End Diaphragm Abutment on Spread Footing

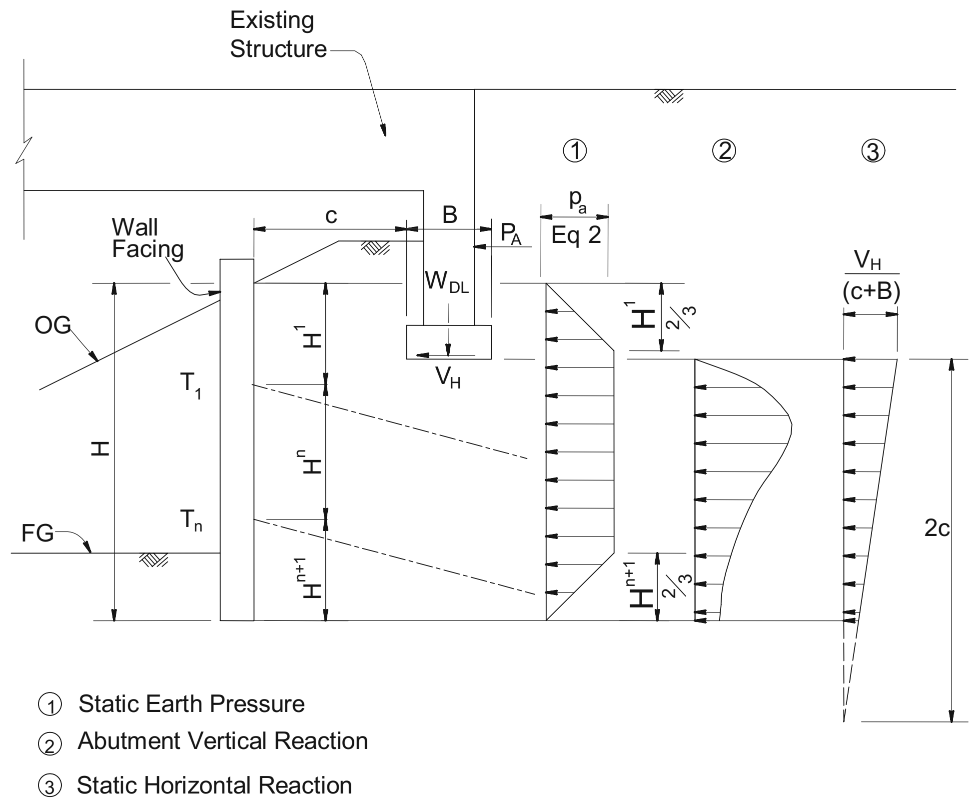


Figure 5-12.11

The trial wedge analysis with Coulomb's theory should be used to determine P_{total}. Assume the $V_H = 0.5\times W_{DL}$ but not less than P_a, and W_{DL} = dead load reaction at base of footing.

Case (d) Seat Abutment on Spread Footing

This case is similar to Case (c).

3. Slope Stabilization Using Ground Anchors

Ground anchors can be used to stabilize unstable slopes. To design ground anchors for slope stabilization, geotechnical analyses should be performed by Geotechnical Services.

The minimum load factor for slopes and landslide stabilization systems is typically 1.35 for static loads, except that a minimum load factor of 1.5 should be used for the case which involves bridge abutments, buildings critical utilities, or other installations for which there is a low tolerance for failure. A minimum load factor of 1.0 should be used for seismic loads.

Request Geotechnical Services to perform geotechnical analysis and design of the slope stabilization systems as outlined in steps 1-9 below.

Step 1 Develop cross section geometry including subsurface stratigraphy, external surcharge loadings, and ground water profile.

Step 2 Assign shear strength and unit weight to each soil and/or rock layer.

Step 3 Select a limit equilibrium method that satisfies both force and moment equilibrium at all potential failure surfaces.

Step 4 Apply any existing surcharges or concentrated forces to the unstable slopes.

Step 5 Use the current conditions obtained from site reconnaisance or subsurface explorations (i.e. Log of test borings, slope indicator (SI) readings, locations of head scarps and toe heaves, mapping of the slide limits, potential slideway surfaces, etc.)

Step 6 Introduce ground anchor forces with different vertical and horizontal spacing, angles of inclination, un-bonded lengths etc., until the target global factor of safety equals 1.5 for permanent service and factor of safety equals 1.3 for temporary service is obtained using unfactored loads.

Step 7 Check the slope configuration during the various stages of construction for any potential lower factor of safety.

Step 8 Evaluate the final configuration under seismic load. A factor of safety of 1.0 or greater must be attained using unfactored loads.

Step 9 Design structural elements forming the entire stabilization system. There are 3 types of structures that could be used for this purpose, as follows:

(A) Reinforced Concrete Walers – Continuous

A horizontal continuous reinforced concrete beam, known as a waler, is used to connect all ground anchors together at the same level, forming a structure frame to buttress the entire slide. This may also be called slope stressing. The design provides adequate flexure and shear capacity with the ground anchor loads as concentrated loads along the waler.

In difficult terrain, or where granular soils comprise the slide debris, a waler constructed using the cast-in-place method is not recommended, instead, the reinforced shotcrete method that conforms to local terrain is recommended. A multi-level ground anchors may be used if necessary based on analysis. The waler must be designed to resist the applied anchor loads and dimensioned to prevent bearing failure of the retained soil.

(B) Reinforced Concrete panels – Discontinuous

Individual blocks, or panel segments connecting ground anchors, at designated locations may also be used to stabilize the slide. The design provides sufficient flexural and shear capacity with the concentrated ground anchor loads on the blocks or panels.

This type of structure could be constructed both with shotcrete and precast blocks or panels. It would require adequate access for hauling and setting up the precast blocks or panels; therefore, limited access to site will not be suitable for precast method. For clayey type of slide debris, large displacement should be anticipated during testing of the anchor. Both single and multiple levels of anchors could be used with this type.

(C) Hybrid Type

When in rugged mountainous terrain, or with a complicated roadway configuration, a single type of structure may not accomplish the task of stabilizing the entire slide; thus a hybrid type of structure becomes necessary. In order to stabilize the unstable downhill slope, buttressing with piling systems may be required. This usually is comprised of soldier piles with ground anchors connecting to a cap beam at the top of piles. Micro-piles with ground anchors on the beam cap could also be used to buttress the downhill side of the roadway embankment. Selection of design configuration should consider, schedule, cost, and aesthetics.

4. Ground Anchors on Concrete Retaining Walls

Vertical or near vertical ground anchors are also called tie-downs as depicted on Bridge Standard Details Sheets, XS 12-030-1 and XS 12-030-2, vertical ground anchors are used to prevent uplifting of the retaining wall footing due to the loads on the sound-wall on top. The design capacity of the stem and the footing is governed by either the wind loads on the sound-wall or by the seismic dead loads of the structure above the footing level. Retaining walls using vertical ground anchors include:

(A) Type 7SW: this type retaining wall is a reversed L shape wall supporting sound-walls on top. See Standard Detail sheets XS-14-380-1 and 14-380-2.

(B) Type 7SWB: this type retaining wall is a reversed L shape wall supporting traffic barrier with sound-walls on top. See Standard Detail sheets XS-14-390-1 and 14-390-2.

Vertical ground anchors could be used also for other scenarios; such as seismic induced uplifting in bridge footings or abutments, high-rise buildings or tower foundations, and hydrostatic forces caused uplifting in gravity dams or underwater structures.

(IV) Ground Anchor Design

General

A ground anchor is a structural element installed in soil or rock that is used to transmit an applied tensile load into the ground. A ground anchor is typically installed in a predrilled hole. The hole is later filled with grout and the anchor prestressed. Components of a ground anchor are described in this section and some of its details can be found in the Bridge Standard Details Sheets (XS sheets Section 12).

Ground anchors can be used for temporary or permanent applications. Temporary ground anchors are used for shoring during construction. Their service life is for the duration of the construction project, usually, two to five years. Permanent ground anchors are required for the life of the permanent structure.

Types of Ground Anchors

The basic types of ground anchors are:

1. Straight shaft gravity-grouted / low-pressure-grouted; these are typically installed in rock, very stiff to hard cohesive soils, and sandy or gravelly soils using either rotary drilling or hollow-stem auger methods.

2. Straight shaft pressure-grouted; these are most suitable for coarse granular soils and weak fissured rock, and are also used in fine grained cohesion-less soils. Grout is injected into the bond zone with pressure greater than 150 psi. A variety of drilling and grouting techniques can be used.

3. Single-under-reamed or multi-under-reamed; these are primarily installed with large uncased drilled holes in cohesive soils and grout is placed with no pressure.

4. Post-grouted; these are installed using delayed multiple grout injections and are used to enlarge the surface area of the grout body of the anchors listed above to increase the load transfer capacity.

A combination of types 1 and 4, or types 2 and 4, are used frequently by the contractors in United States. Ground anchor capacity is based upon developing the friction and adhesion of the soil along the soil-anchor interface, or for under-reamed (belled-end) anchors, the shear strength of the soil at the surface of a cylindrical plug with a diameter equal to that of the bell. The resistance along the soil-anchor interface is a function of the contractor's method of installation. The design of the anchor type and any anchor length beyond the specified length of the un-bonded zone is the responsibility of the contractor.

Components

The basic components of ground anchor include:

1. Anchorage – A device usually consisting of a plate and an anchor head with wedges (or threaded nut), which permits the stressing and locking-off of the anchor.

2. Pre-stressing steel – Commercially available in single or multiple wires, strands, or high strength bars comprising: (a) the bonded length – that portion of the pre-stressing steel fixed in the primary grout bulb, through which load is transferred to the surrounding soil or rock, and (b) the un-bonded length – that portion of the pre-stressing steel which is free to elongate elastically and transmit the resisting force from the bonded length to the structural elements (i.e. the wall face, etc.).

3. Grout – A Portland cement based mixture, which provides corrosion protection as well as the medium to transfer load from the pre-stressing steel to the soil or rock.

Design

For preliminary design the design pullout resistance of anchors may be estimated based on the review of geotechnical data, soil and rock samples, laboratory tests, and previous experience, or published soil and rock to grout bond strength. If necessary consult with Geotechnical Services. Final design of the bonded length is generally the responsibility of the contractor and is verified by load test of each anchor.

The anchor bonded length shall be located beyond the limits of the potential active zone. A minimum distance between the front of the bonded zone of the anchor and the limits of the potential active zone behind the wall of 5 feet or $H/5$ is needed to ensure that no load from the bonded zone of the ground anchor is transferred to the retained soil mass by the grout column. The limits of the potential active zone should be provided by Geotechnical Services.

Determination of the anchor un-bonded length, inclination from horizontal and overburden cover shall be based on:

1. The location of the limits of the potential active zone behind the wall,

2. The minimum length required to ensure minimal loss of anchor pre-stress due to creep of soil and rock, but not less than 15 feet,

3. The depth to adequate anchoring strata,

4. The method of anchor installation and grouting,

5. The seismic performance of the wall and anchors.

The minimum spacing between ground anchors should be the larger of three times the diameter of the hole within the bonded length, or 5 feet, to avoid group effects of the anchors. If tighter spacing is required to develop the required anchor design force, the angle of inclination can be varied on alternating anchors.

Based upon past experience, the majority of ground anchors are small diameter, straight shaft gravity-grouted anchors with the following typical characteristics.

(A) Design Load between 60 and 240 kips

Anchor tendons of this capacity can be handled without the need for heavy or specialized equipment. In addition, the stressing equipment can be handled by one or two workers without the aid of mechanical lifting equipment. The drilled hole diameter is generally 6 inches or less, except for hollow stem auger anchors that are typically 12 inches in diameter.

(B) Total Anchor Length between 30 to 60 feet

Because of geotechnical or geometrical requirements, very few anchors for retaining walls or for tie-down structures are less than 30 feet long. A minimum un-bonded length of 10 feet for bar tendons and 15 feet for strand tendons should be adopted. This would avoid the unacceptable load reduction resulting from seating losses during load transfer, and pre-stress losses due to creep both in the pre-stressing steel or the soil.

(C) Ground Anchor Inclination between 10 to 45 degrees

Generally, anchors should be installed as close to horizontal as possible to minimize vertical forces imposed on the wall elements resulting from the lock-off loads. However, a minimum angle, measured down from the horizontal, is required to ensure the grout completely fills the hole in the bonded length to permit load transfer and to ensure adequate overburden cover for shallow anchors (a minimum of 15 feet over the bonded length). An inclination of 15 to 30 degrees is commonly used. Steeper angles are only recommended to reach deep anchoring strata or to avoid existing underground structures, adjacent foundations, or right-of-way constraints. Shallower angles will require some special grouting techniques.

For a specific project, the first step in estimating the minimum allowable capacity is to determine what maximum bonded length is allowed. For example, in the case of a site with no restrictions on right-of-way, an assumed bonded length at 15 degree inclination would be 40 feet in soil and 25 feet in rock. Anchors founded in mixed ground conditions, soil and rock, should be designed assuming the entire embedment is soil; i.e., bonded length equal to 40 feet. The bonded length at sites with more restricted right-of-way may be found by assuming an anchor inclination of 30 degrees and determining the distance from the end of the free length to within 2 feet of the right-of-way line.

Pre-stressing steel design is based on a maximum stress of $0.75f_{pu}$ at factored test load (*FTL*). (f_{pu} = specified minimum ultimate tensile strength.) The factored design load "*FDL*", the *FTL*, and the lock off load "*LL*" for each anchor should be indicated on the plans.

Testing

A unique aspect of ground anchors, as compared to other structural systems, is that every anchor in the completed structure is load tested after installation to verify its load capacity and load deformation behavior prior to being put into service. This load testing methodology, combined with specific acceptance criteria, is used to verify that the ground anchors can carry the design load without excessive deformations and that the assumed load transfer mechanisms have been properly developed behind the assumed critical failure surface. After acceptance, the ground anchor is stressed to a specified load and locked-off. The acceptance or rejection of ground anchors is determined based on the results of:

1. Performance tests;

2. Proof tests;

3. Extended creep tests.

In addition, shorter duration creep tests (as opposed to extended creep tests) are performed as part of the performance and proof tests. Proof tests are the most common and are performed on the majority of the ground anchors for a project depending upon whether the anchors are for a temporary support of excavation or permanent application and the type of ground.

The *FTL* for each ground anchor shall be 1.0 times or greater than the factored design load "*FDL*".If the seismic load is greater than the *FDL*, the *FTL* shall be 1.0 times the seismic load.

Subsequent to successful testing, the anchor should be stressed to a specified load and locked off against the structure. For most earth retaining structures the recommended lock off load, *LL* equals 0.55*FDL*. An exception to this is when it is desired to minimize structure movement, in which case the recommended lock off load equals 0.67 *FDL*. Examples of this situation are the earth retaining structures supporting the bridge abutments, buildings, critical utilities, or other installations for which there is a low tolerance for failure.

Corrosion Prevention

Protecting the metallic components of the tendon against the detrimental effects of corrosion is necessary to ensure adequate long-term durability of the ground anchors. Corrosion protection for ground anchor tendons includes either one or more physical barrier layers, which protect the tendon from the corrosive environment. To protect the three major parts of the tendons, the following barrier layers are used:

1. The anchorage – an anchorage cover, or concrete embedment, a trumpet, and corrosion inhibiting compounds or grout;

2. The un-bonded length – grout and sheathing filled with corrosion inhibiting compound. Also heat shrink sleeves for the couplers that are used for the pre-stressing bars;

3. The bonded length – grout and epoxy coatings, or full encapsulation with centralizers.

The selection of the physical barrier depends on the design life of the structure (i.e. temporary or permanent), the aggressiveness of the ground environment, the consequences of failure of the anchored system, and the additional cost of providing a higher level of protection.

Only a few anchor failures due to corrosion of the pre-stressing steel and/or anchorage have been reported. However, most of those failures have occurred within 6 feet of the anchorage. Extra attention should be given when installing corrosion protection at this part of the tendon. Next to the anchorage, the pre-stressing steel in the un-bonded length is the most vulnerable to corrosion. Thus, sheathing filled with corrosive inhibiting grease is required. No corrosion failures have been reported when the tendon has been properly grouted.

Encapsulations are used for Class I protection (PTI, 2004) of the tendon bond length. Encapsulation may be pre-grouted or grouted on-site after insertion of the tendon into the drill holes. Standard detail sheets XS–12–030–1, XS–12–030–2 and XS–12–040 illustrate the options of different types of tendons with Class I corrosion protection. The materials specifications and corrosion requirements are covered in the Standard Specifications.

(V) Plans and Specifications

Plans

The soil and rock design parameters such as unit weight (γ), friction angle (ϕ), and cohesion (c), should be shown in the General Notes indicating that these values are for the earth retaining structures design only. Information shown on the plans for an earth retaining structure with ground anchors usually includes but is not limited to the following:

1. The factored design load "*FDL*", the factored test load "*FTL*" and the lock off load "*LL*" of ground anchors.

2. Position and angle of inclination of ground anchors;

3. Minimum un-bonded length of ground anchors;

4. Concrete compressive strength required at time of stressing.

References

1. AASHTO LRFD BDS. 4th Edition (2007) with California Amendments (2011)

2. FHWA / RD-82 / 047 “Tiebacks” (1982)

3. FHWA – DP – 68 – 1 “Permanent Ground Anchors” (1984)

4. FHWA – DP – 68 -1R “Permanent Ground Anchors” (1988)

5. FHWA – RD – 98 – 065 “Summary Report of Research on Permanent Ground Anchor Walls, Vol. 1, Current Practice and Limiting Equilibrium Analyses.” (1997)

6. FHWA – RD – 97 – 130 “Design Guidelines for Permanent Ground Anchors” (1998)

7. FHWA – SA – 99 – 015 “Geotechnical Engineering Circular No.4: Ground Anchors And Anchored Systems” (1999)

8. PTI – “Recommendations for Pre-stressed Rock and Soil Anchors” (2004)

9. California Department of Transportation, Bridge Design Specification. Section 5 – Retaining Walls (2004)

10. California Department of Transportation, Correspondence Course Outline - Earth Retaining Structures

11. California Department of Transportation, Structure Reference Specifications (2006)

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