Ground Anchor Earth Retaining Systems (ERS)

This module presents Caltrans practice for geotechnical investigation, design, and reporting of ground anchor ERS. A brief discussion of the design policy and procedures on Deadman ERS is also included at the end of the design section. In this module, ground anchors are referred to as sub-horizontal ground anchors.

A ground anchor ERS is constructed by installing rows of ground anchors to resist lateral loads acting on the wall. They are commonly used for embankment roadway re-construction and stabilization where space for re-grading is limited. Soldier pile ground anchor walls are most common; concrete diaphragm ground anchor walls are commonly used for roadway widening projects under the bridge abutments (see *Memo to Designers 5-12*, “Earth Retaining Systems Using Ground Anchors”). A ground anchor system consists of three components: anchorage (anchor head assembly), free stressing tendon (unbonded length), and anchor (bonded length) (Figure 1). Ground anchors provide lateral resistance by pre-stressing the tendon from the anchor to the anchorage at the wall facing. The ground anchor tendon can be either steel bars or steel strands; steel strands are more commonly used as they can provide higher tensile resistance and be easily handled during installation.

Design and performance advantages of ground anchor ERS include:

- Cost effective compared with most other ERS using top-down construction methods
- Less disruptive to traffic than ERS using bottom-up construction methods
- Less environmental impact than ERS using bottom-up construction method
- Quality assurance through performance or proof tests on each anchor
- ‘Active’ system to minimize lateral movement during excavation by pre-stressing of each anchor

Ground anchor ERS are unfavorable when there are:

- Permanent easement requirements
- Underground utilities or structures within the anchor zone

Favorable subsurface conditions for ground anchor ERS are:

- Excavated face can stand unsupported and stable until the facing is structurally complete
- Drilled holes can remain open and stable without casing until the anchor is placed and grouted.

Unfavorable subsurface conditions for ground anchor ERS include:

- Soft, highly plastic clay, organic soil, collapsible soil, expansive soil, cobbles and boulders, weathered rock with unfavorable bedding planes

- Groundwater table is above design grade for soldier pile ground anchor walls
- Very weak soils behind the wall facing

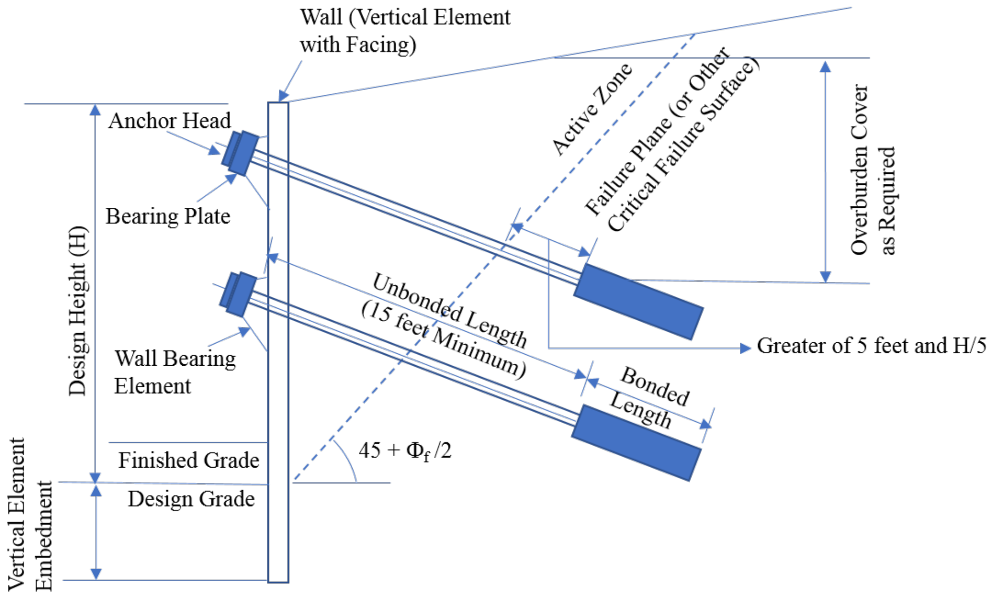

Figure 1: Ground Anchor ERS Components (Modified after AASHTO LRFD BDS)

Design Manuals and Guidelines for Design

For ground anchor ERS design, use this module, and the following design manuals and guidelines:

- *2017 (8th Edition) AASHTO LRFD Bridge Design Specifications* and *2019 California Amendments* hereafter "AASHTO"
- *Memo to Designers 5-12*, "Earth Retaining Systems Using Ground Anchors"
- *Memo to Designers 5-19*, "Earth Retaining Systems Communication"
- *Geotechnical Manual,* "Geotechnical Seismic Design of Earth Retaining Systems"

For design cases where guidance provided in the above documents is not applicable, refer to other FHWA reference manuals including *FHWA NHI-05-094*, "LRFD for Highway Substructures and Earth Retaining Structure" *and FHWA Geotechnical Engineer Circular No. 4*, "Ground Anchors and Anchored Systems".

Geotechnical Services' Responsibilities for Design

Geotechnical Services' responsibilities in the design of ground anchor ERS are:

- Develop interpreted subsurface cross sections; for a long wall, development of more than one cross section along alignment, depending on variability of surface conditions, may be needed
- Determine engineering properties of subsurface materials such as unit weight, cohesion or undrained shear strength, friction angle, and associated lateral earth pressure coefficients
- Analyze lateral earth pressure and its distribution for complex wall geometries when conventional earth pressure theories are not applicable or when requested by the structure designer
- Analyze minimum pile embedment depth based on global stability requirement and required axial capacity, if pile elements are used.
- Analyze anchor unbonded zone length based on conventional earth pressure theory if applicable, or slope stability analysis
- Assist the structure designer or the district project engineer in determining necessary permanent easements

Information that should be provided by the structure designer for geotechnical analysis and design are:

- Plans showing the location of wall (begin and end, length and alignment)
- Elevation view of wall (maximum and minimum design height)
- Cross sections of wall (e.g., every 10 to 50 feet)
- Topography with cross sections depicting the slip-out or erosion of slope face for slope stabilization application (this information can be directly provided by District)

For the design of ground anchor ERS, assist the structure designer by providing all applicable lateral pressures against the wall including static and seismic earth pressure, lateral pressures induced by surcharge load, and hydrostatic pressure.

Geotechnical Investigation

Perform a geotechnical investigation to determine subsurface conditions that may affect the selection, design, and construction of the ground anchor ERS, including:

- Strength and deformation characteristics of foundation soils and rocks
- Strength and weight of soils and rocks to be retained
- Corrosion potential of soils in contact with the retaining wall
- Groundwater location
- Quantity of groundwater seepage

Typical borehole spacing is about every 100 to 200 feet along the proposed wall alignment, with boreholes strategically positioned in front, behind, and directly on the retaining wall layout line. Perform at least one horizontal boring, if feasible, into the slope that is to be excavated and drilled for ground anchor wall construction to obtain soil and rock specimens and evaluate the caving potential of drilled holes during construction. The number of boreholes may be reduced or increased based on the quality of existing data, uniformity of site geology, and the quality of site-specific geologic mapping. The depth of investigation should be more than two times the design height of the ERS or 20 feet below the ERS design grade, whichever is greater.

Design

The geotechnical design of a ground anchor ERS must meet displacement and stability requirements for the following limit states defined by LRFD design methodology:

- Service Limit State – movement and overall (global) stability (*AASHTO LRFD BDS* Article 11.9.3)
- Strength Limit State – stability against soil failures such as bearing failure (geotechnical axial capacity of vertical elements), anchor pullout failure, and passive failure due to insufficient vertical element embedment (*AASHTO LRFD BDS* Article 11.9.4)
- Extreme Limit State - stability against soil failures such as bearing failure (geotechnical axial capacity of vertical element), anchor pullout failure, and passive failure due to insufficient vertical element embedment, and overall/global stability (*AASHTO LRFD BDS* Articles 11.9.4 and 11.9.6)

For each of the limit states, the load and resistance factors should be applied in accordance with AASHTO 3.4.1 (Table 3.4.1-1) and 11.5.6 and *California Amendments* (Table 11.5.7-1).

Lateral Pressure Calculation

The magnitude and distribution of lateral pressures depend upon wall type, wall movement, wall geometry/stiffness, friction at wall-soil interface, retained soil type, groundwater conditions, earth surcharge/sloping ground conditions, traffic, and construction related live load surcharge. These factors should be considered for the calculation of lateral pressures.

<u>Static Lateral Pressure</u>

- Apparent Earth Pressure (AEP)

  Calculation of AEP must follow AASHTO 3.11.5.7, and *Caltrans MTD 5-12*. The AEP was developed from top-down construction with constraining or limiting wall deformation and should be used whenever the construction method meets these conditions. The distribution of AEP should be based on construction method and sequence, stiffness of wall and anchor system, type and properties of soils, pile and anchor spacing, and expected displacement, etc.

For simple wall geometry, and subsurface profiles in which the Rankine or Coulomb active earth pressure coefficient can be used for calculation of AEP, use AASHTO Equations 3.11.5.7.1-1 to 3.11.5.7.2b-2 and AASHTO Figures 3.11.5.7.1-1 and 3.11.5.7.2b-1. When calculating active earth pressure coefficient, k_a, the wall interface friction angle should be equal to zero for both Rankine and Coulomb. For walls with cohesive soil conditions, both short-term condition (undrained) and long-term (drained) condition should be evaluated, and AEP should be developed for the condition, whichever results in greater lateral force.

For complex wall geometry, or subsurface profiles in which the Rankine or Coulomb earth pressure coefficient cannot be used for calculation of AEP, use Equations 5-12.1 and 5-12.2 of *Caltrans MTD 5-12*. Consider a total load, P_{total} as a total lateral load of AEP (P_{AEP}) in these equations. When calculating the P_{AEP} by the Limit Equilibrium (LE) analysis, use the following methods: Method 1 and Method 2.

Note that a multiplier of 1.33 is introduced in Method 1 to account for the effect of construction method (ground anchor installation with pre-stressing). The multiplier was calibrated for cohesionless soil by comparing field measured earth pressure force with active earth pressure force. Therefore, do not use Method 1 with a multiplier of 1.33 for cohesive soil. Furthermore, do not use Method 2 for stiff to hard clay soils because the LE stability analysis using undrained shear strength is misleading for stiff clays. Stiff clays can be self-supporting, and no additional stabilizing force may be necessary to support the wall. When a drained analysis is performed on the stiff to hard clay soils with effective strength parameters, Method 2 may be used with caution.

- Method 1 – for Cohesionless Soil

  Perform LE (slope stability) analysis for stability of the retained soil mass, and find the required stabilizing (active) force, P_A ($P_A = P_{FoS\_1.0}$) resulting in a factor of safety (FoS) of 1.0. The FoS of 1.0 is equivalent to the active earth pressure condition. Then multiply the P_A by 1.33 to obtain the P_{AEP} ($P_{AEP} = 1.33\ P_A$). The multiplier of 1.33 was also used in deriving the AASHTO Equations 3.11.5.7.1-1 to 3.11.5.7.2b-2.

$$P_{AEP} = \frac{2K_a\gamma H^2}{3} = 1.33 \times \left(\frac{K_a\gamma H^2}{2}\right) = 1.33 \times P_A$$

  Where,

  P_{AEP} = Total force per unit length of a wall based on AEP distribution (Figures 3.11.5.7.1-1 (a), and AASHTO Equations 3.11.5.7.1-1 (b).

  P_A = Total force per unit length of a wall based on triangular distribution of active earth pressure.

- Method 2

  Perform LE slope stability analysis and find the required stabilizing force per unit length of a wall, $P_{FoS\_1.33 \text{ or } 1.54}$, resulting in a factor of safety (FoS) of 1.33 or 1.54. The calculated stabilizing force should be considered as the P_{AEP} ($P_{AEP} = P_{FoS\_1.33 \text{ or } 1.54}$). Do not apply the multiplier of 1.33 used in Method 1 to P_{AEP}. According to AASHTO, a resistance factor of 0.75 (equivalent to FoS of 1.33) is recommended for well-defined soil parameters and a slope that is not supporting structures, while a resistance factor of 0.65 (equivalent to FoS of 1.54) is recommended for limited soil information and a slope that is supporting structures.

Method 2 is commonly used for slope stabilization or landslide mitigation. According to *FHWA Geotechnical Engineer Circular No. 4*, "Ground Anchors and Anchored Systems", $P_{FoS\_1.3}$ is close to $1.3P_{FoS\_1.0}$ for reasonably homogeneous sandy soils with competent soils below the bottom of excavation. For walls supporting critical structures, $P_{FoS\_1.5}$, a higher value, may be used for P_{AEP} to reduce wall deformation and its effect on nearby structure. The P_{AEP} ($P_{FoS\_1.33 \text{ or } 1.54}$) calculated from Method 2 should not be less than the P_{AEP} ($1.33\ P_A$) calculated from Method 1.

When soft or very loose soils exist below the bottom of excavation, and basal stability is of concern, extend LE analysis below the design grade. However, ground anchor ERS may not be suitable at sites with soft soils that extend to a significant depth below the design grade.

In addition to AEP, appropriate hydrostatic water pressure, lateral pressures induced by surcharge load, and seismic earth pressure should be included in the analysis.

- Surcharge Load

  Use AASHTO 3.11.6 for the lateral pressure against the wall induced by surcharge loads.

- Hydrostatic Water Pressures

  When water is present behind the wall, hydrostatic water pressure must be considered in the design in addition to other lateral earth pressures. When the hydrostatic water pressure is applied to the wall, calculate lateral earth pressure including apparent earth pressure with effective unit weight of soils. For ground anchor ERS with continuous wall facing such as sheet piles, tangent piles and secant piles, hydrostatic pressure differential can develop between the back and front of the wall face and can cause seepage or piping (boiling) in cohesionless soils. For such cases, perform seepage analyses using the flow net or numerical analysis to ensure base stability against seepage. Section 5.2.9 of *FHWA Geotechnical Engineering Circular No. 4*, "Ground Anchors and Anchored Systems" presents procedures to calculate porewater pressure considering effects of seepage (Equations 15 to 17, and Figure 32), and simplified flow net for homogeneous soil (Figure 31). For non-homogeneous soil or special drainage conditions which may alter water boundary conditions, use numerical seepage analysis.

- Passive Earth Pressure

  For the calculation of passive earth pressure, use the log-spiral method with an appropriate wall interface friction angle. When the log-spiral method can't be used due to complex geometry or multiple soil layers, use the Trial Wedge Method with the wall interface friction angle of no greater than 0.5Φ as per AASHTO 3.11.5.4, where Φ is friction angle of the soil.

  When AASHTO Figures 3.11.5.6-1, 2, 4 and 5 are used for calculation of passive earth pressure against embedded discrete vertical elements, use the Rankine passive earth pressure coefficient. The figures were developed based on Broms Method (1964), in which the Rankine passive earth pressure coefficient was used to derive the effective width of 3 times the pile diameter. When different soil arching factors need to be used in the design, refer to AASHTO C11.8.6.3.

Seismic Lateral Earth Pressure

For calculation of seismic lateral earth pressures, use AASHTO 11.6.5.2, 11.8.6 and 11.9.6. All the seismic loads for the design of non-gravity cantilever ERS are shown on AASHTO Figure 11.8.6.2.1. As shown on Figure 11.8.6.2.1, a seismic active earth pressure resultant, P_{AE} is considered only above the design grade, while P_A and P_{PE} are applied below the design grade. In addition, according to AASHTO C11.8.6.2, for walls with continuous vertical elements, such as sheet pile walls, tangent pile walls, and secant pile walls, the P_{AE} will be distributed from top of wall to a point where the critical failure plane of LE analysis intersects the vertical element below design grade. For walls supporting seismic critical structure, seismic active earth pressure should be extended below the design grade to the toe of the vertical element to account for uncertainties in the seismic distribution below design grade. For more information on how to determine the design horizontal seismic coefficient to be used in the calculation of seismic earth pressures, refer to *Geotechnical Seismic Design of Earth Retaining Systems*.

- Seismic Active Earth Pressures

  For the calculation of seismic active earth pressures, use AASHTO 11.6.5.3. These standards present three methods to calculate the seismic active earth pressure: Mononobe-Okabe (M-O) Method, Trial Wedge method, and Limit Equilibrium (LE) Method. For wall geometry or site and soil conditions for which the M-O Method is not suitable, either Trial Wedge method or LE method can be used.

  Because seismic horizontal acceleration and resulting seismic earth pressure greatly depends on the magnitude of seismic displacement of a ground anchor ERS, consult the structure designer for tolerable permanent seismic displacement of a ground anchor ERS, and assist the structure designer in estimating the design horizontal seismic coefficient (k_h). The k_h associated with the tolerable permanent seismic displacement should be used for calculating seismic active earth pressures.

When wall displacement analyses using numerical methods such as finite element or finite difference methods, and the beam-column approach are to be performed by the structure engineer, soil spring parameters such as p-y curves should be provided by the geoprofessional according to AASHTO C11.8.6.4.

- Seismic Passive Earth Pressures

  For calculation of seismic passive earth pressures, use AASHTO 11.8.6.3 and A11.4. In these articles, the log spiral procedure or the nonlinear failure surface are recommended to be used with the wall interface friction. Do not use the M-O Method for estimating the seismic passive earth pressure. According to AASHTO 11.6.5.5, a wall interface friction equal to two-thirds of the soil friction angle can be used for the calculation of the seismic passive pressures when there are no specific guidance or research results for a seismic wall interface friction. For the wall with embedment depth less than 5 feet below finished grade, use the static method for the seismic passive pressure according to AASHTO 11.6.5.5. For non-gravity cantilever walls using solider piles, use the static method according to AASHTO 11.8.6.3.

Limit State Design

The design of ground anchor ERS must meet displacement and stability requirements for each limit state below, and appropriate scour must be considered in each limit state if the wall is in a flood prone area. For the guidance related to scour evaluation, refer to AASHTO and California Amendment 2.6.4.4.2 and 11.7.2.3.

Service Limit State

<u>Displacement</u>

The design of the wall must ensure that the vertical and lateral displacement does not affect the performance of the wall system. For calculation of settlement of the wall system use AASHTO Figure C11.9.3.1-1. For walls supporting low-displacement tolerance structure, numerical analysis such as finite element or finite difference methods may be required. For ground anchor ERS constructed by excavating a vertical face, there is no vertical stress increase in soils, and settlement due to net vertical stress does not occur.

<u>Global Stability</u>

The global stability is evaluated using acceptable methods of LE slope stability analysis such as Morgenstern-Price, Modified Bishop, Janbu, or Spencer methods. For the resistance factors used in the global stability, refer to AASHTO 11.6.2.3.

Strength Limit State

Axial capacity of vertical element (bearing failure)

For calculation of axial capacity of a vertical element, use AASHTO 10.7 through 10.9 and Caltrans Pile Foundations Manuals. Embedment depth of vertical elements must withstand factored axial load demands induced by the vertical component of total anchor loads, dead weight of the wall system and other external loads.

Basal Heave Stability

For walls embedded/supported on soft to medium clays, check basal heave stability to ensure adequate soil bearing capacity at the base of the excavation and no substantial increase in lateral earth pressure. The methods (Equations 34 to 37) to calculate a factor of safety against basal heave stability are presented in Section 5.8.2 “Basal Stability” of *Geotechnical Engineering Circular No. 4*, “Ground Anchors and Anchored Systems.” According to Section 5.8.2, significant ground movements towards the excavation will occur when the soil bearing capacity at the base of excavation is approached regardless of the strength of the supports, and it will substantially increase the load on the lowest ground anchor with decreasing FoS of basal heave stability. *Geotechnical Engineering Circular No. 4* recommends the minimum FoS of 1.5 for support of the excavation. Because there is no LFRD guideline on basal heave stability, allowable stress design (ASD) with the minimum FoS of 1.5 can be used until LRFD guidelines on basal heave stability is available in AASHTO.

Anchor Pullout

Determination of anchor pullout resistance and corresponding anchor bond length are the Contractor’s responsibility.

Minimum Anchor Unbonded Length

For determination of the minimum anchor unbonded length, refer to AASHTO 11.9.1., 11.9.4.2, C11.9.4.2, and Figure 11.9.1-1. For complex wall geometry, or subsurface profile for which Figure 11.9.1-1 cannot be used, use LE slope stability analysis for the minimum anchor unbonded length. The minimum anchor unbonded length is the distance from wall face to the failure surface plus a minimum distance between potential failure surface and frontal anchor bond zone, 5 feet or H/5, whichever is greater. According to AASHTO Figure 11.9.1-1, H is defined as design height of vertical element above design grade.

Extreme Event Limit State

Minimum Anchor Unbonded Length

For determination of the minimum anchor unbonded length, use AASHTO 11.9.6. For LE slope stability analysis, use the k_h associated with a tolerable seismic permanent displacement of ground anchor ERS.

Seismic Global Stability

For seismic global stability analysis, use AASHTO 11.8.6.1 and 11.9.3.2. There are two benchmark values for k_h used in the seismic global stability analysis depending on tolerable seismic displacements: 1/2 or 1/3 horizontal peak ground acceleration (HPGA), which is the acceleration at zero period (T =0) calculated from Caltrans ARS Online (v.3.0). Use k_h of 1/3 HPGA if a mean seismic permanent displacement of about 4.0 inches is acceptable. Use k_h of 1/2 HPGA if the maximum 2.0-inch seismic displacement is acceptable. For details of the seismic global stability analysis procedure, refer to *Geotechnical Seismic Design of Earth Retaining Systems*.

Ground Anchors for Slope Stabilization

Ground anchors can be paired with either a structural reaction frame or an ERS, i.e. soldier piles with lagging, to stabilize a slope. Three types of structural reaction frames are commonly used in Caltrans projects: continuous reinforced concrete beam (known as waler), discrete reinforced concrete blocks, and a hybrid system. The selection of ground anchor reaction frame types or ERS depends on project-specific requirements and constraints, including right of way, construction easement, accessibility and the condition of the slope or highway foundation to be stabilized. Compared to ground anchor ERS, ground anchors with structural reaction frames are more suitable and cost-effective when extensive re-grading or excavation of the slope is not needed or can be reduced to the minimum as the structural reaction frames are placed on and against the slope surface. On the other hand, ground anchor ERS for slope stabilization requires excavation of the slope in front of the wall to install the ground anchors.

Design Considerations

- Ground Anchor with Structural Reaction Frame

  For the design of ground anchor with structural reaction frames, include only the ground anchor force in the slope stability analysis model. The following are the geotechnical design steps for ground anchor with structure reaction frames:

  1. Determine and enter ground anchor design parameters such as inclination angles, locations (vertical spacings for multiple rows of anchors), and a stabilizing anchor force (kips/ft) (a point load on slope surface) at each anchor location into a slope model and perform slope stability analysis to arrive at the

optimal ground anchor design that satisfies the minimum factor of safety of the slope.

2. Determine a minimum size of the reaction frame (width and/or length) based on the determined anchor force in step 1 and bearing capacity of a reaction frame at each anchor location. For granular soils where bearing capacity varies with footing dimensions, iterative process is necessary to arrive at the minimum size.
3. Provide the following ground anchor design parameters and a minimum size of the reaction frame for the design of structural reaction frame:
    a) Anchor force (kips/ft) at each anchor location
    b) Anchor inclination angle with respect to the horizonal line
    c) Unbonded anchor length
    d) Minimum reaction frame width and/or length

- Ground Anchor ERS – Soldier piles with Lagging

  For the design of ground anchor ERS for slope stabilization, follow ground anchor ERS design described in Design section. Use Method 2 for the determination of the magnitude and distribution of apparent earth pressure.

  For the required minimum factor of safety of a stabilized slope, refer to *Landslides and Soil Cut Slopes*. When bridge abutment or any critical structure with low tolerance of failure are involved in slope stabilization, use a minimum factor of safety of 1.5. Refer to *FHWA IF-99-015 Section 5.7 Anchored Slopes and Landslide Stabilization Systems* for ground anchor design concepts and methods using limit equilibrium method (slope stability computer program).

  When creep and associated loss of pre-stressed anchor load is a concern in the performance of ground anchors, consider increasing the number of ground anchors to lower the load demand per anchor while assuring a minimum center to center spacing of three times drilled hole diameter. For soft to very soft cohesive soils or materials with high organic contents that are highly susceptible to creep, ground anchor system should not be used.

Ground Anchor Construction Quality Assurance

Quality assurance testing of ground anchors is an important part of a project. Every ground anchor is to be tested to verify the adequacy of the contractor’s drilling and grouting operations, load transfer mechanism, and its load-carrying capacity with specific acceptance criteria on creep deformation. Types and purpose of ground anchor tests are summarized in following table:

Table 1: Type and purpose of Ground Anchor Construction Quality Assurance Tests

Type	Purpose	Sacrificial or Production Anchor	Test Load (often called as Factored Test Load)	Lock-Off Load
Verification Test (Preproduction Pullout Test)- five load cycle	Verify grout/ground bond strength as well as creep and load-deformation behavior	Sacrificial Anchor	Factored design load (FDL) divided by resistance factor or seismic load whichever greater	N/A
Performance Test – five load cycle	Verify anchor capacity to resist test load as well as creep and load-deformation behavior.	Production Anchor	Factored designed load (FDL) or seismic load whichever greater	0.55 FDL to 0.75 FDL
Proof Test – one load cycle	Verify anchor capacity to resist test load as well as creep behavior	Production Anchor	Factored designed load (FDL) or seismic load whichever greater.	0.55 FDL to 0.75 FDL

Performance and Proof Tests

For details of loading schedules and acceptance criteria, refer to Caltrans Standard Specifications 46-2-01D(b) and 46-2.01D(3).

For performance testing, recommend a minimum of 3 anchors per wall zone but at least 5 percent of total production anchors. All remaining production ground anchors are subjected to proof tests.

After successful ground anchor tests, the anchor is stressed to a specified load (lock-off load) and lock off against the structure element. A lock-off load of 0.55 FDL is recommended for most ground anchor walls in Caltrans. However, when ground anchors support bridge abutments or any critical structures with a low tolerance of failure or displacement, recommend a lock-off load of 0.67 FDL. For the ground anchors to stabilize slopes, a lock-off load may be equal to or greater than 0.75 FDL. However, when recommending a higher lock-off load, associated creep displacement and loss of pre-stressed load in the anchors should be expected and considered for the performance of the ground anchor system.

Verification Tests (Preproduction Pullout Tests)

Caltrans practice in ground anchor installation allows single-stage grouting, by which both anchor bond length and unbonded length are grouted in one stage. Single-stage grouting will cause load-transfer of unknown magnitude through the grout column (unbonded length) above the anchor bond length. The load transfer can lead to erroneous interpretation of ground anchor capacities. When unknown load-transfer to the unbonded zone and/or verification of nominal ultimate bond strength and adequacy of design bond length determined by the Contractor are of concern for a specific project, verification tests can be recommended. Refer to *AASHTO LRFD BDS 11.9.8.1 and C11.9.8.1* where verification testing is called the preproduction pullout test. Sacrificial verification test ground anchors are installed with only the bond length grouted for testing.

Since the verification test is not a standard test for Caltrans projects, Non-Standard Special Provisions (NSSP) shall be developed when needed. Before recommending verification tests, consult with Structure Design and Structure Construction about any structural or construction issues or constraints that should be considered for the efficiency and feasibility of tests. For example, when an unusually large structural reaction frame is needed due to a high-test load, one option is to test sacrificial ground anchors to the maximum performance test load by allowing the bond length to be reduced. This approach is only suitable when material properties in the bond zone are uniform.

The Ground Anchor Verification Test nSSP (section 46-2) is available on the NSSP for Geotechnical Design intranet page. Use this nSSP and modify it as necessary for any project-specific requirements. The factored test load (FTL) of the verification test shall be taken as the factored design load divided by a resistance factor or seismic, whichever greater. For the resistance factor for presumptive ground anchor pullout resistance, refer to *California Amendments to AASHTO LRFD BDS* Table 11.5.7.1.

Deadman

Design guidelines for deadman anchors are not presented in AASHTO. If the deadman anchors are needed, use *Caltrans (LFD Version) Bridge Design Specifications (BDS)* Article 5.8.6.2 (2003). In *Caltrans BDS*, a deadman is termed a structural anchor. The deadman typically consists of a concrete anchor with large masses of precast or cast-in-placed concrete (*Caltrans BDS* Article 5.8.6.2.1), an anchor pile with driven or cast-in-drilled-hole (CIDH) piles (*Caltrans BDS* Article 5.8.6.2.2) and pile anchors with driven piles (*Caltrans BDS* Article 5.8.6.2.3). According to *Caltrans BDS* Article 5.8.6.2.1, the depth of the concrete anchor deadman shall be based on the active and passive earth pressures behind and in front of the deadman, and the deadman must be located far enough from the wall face to ensure the passive zone in front of the deadman does not overlap with active zone behind the wall.

For the design of the deadman, allowable stress design (ASD) may need to be used until resistance factors for the design of the deadman are calibrated and published in AASHTO. Before recommending and designing the deadman anchor, verify with the structure designer whether ASD or LRFD will be used.

Unlike ground anchor ERS, in which AEP is used in the design, *Caltrans BDS* Article 5.8.2 recommends active earth pressure with triangular distribution for design of the deadman anchors. The recommendation of the active earth pressure with triangular distribution may indicate that the deadman is a passive anchorage with no pre-stressing, and the anchor is activated when the retained mass is deformed.

Reporting

Present recommendations for ground anchor earth retaining systems (ground anchored pile systems, anchored diaphragm walls) in accordance with the *Foundation Reports for Earth Retaining Systems* module. Present the following in the *Geotechnical Recommendations* section of the Foundation Report.

Design Parameters

Provide the magnitude and distribution of lateral earth pressure along vertical wall elements or provide the engineering properties required for the calculation of lateral earth pressure. For walls with simple geometry and homogeneous soils, provide the following engineering properties for foundation soils and rocks below design grade and retained soils and rocks behind the wall:

- Moist unit weight
- Cohesion
- Friction angle
- Rock strength
- Static earth pressure coefficients
- Horizontal seismic coefficient with expected displacement
- Seismic earth pressure coefficients
- Design groundwater elevation

For walls with complex geometry, inhomogeneous soils, or cohesive soil layers, or when requested by Bridge Design, provide the following additional information:

- Static AEP diagram, or total stabilizing force (unfactored), P_{AEP} for retained soils
- Static earth pressure diagram, and static earth pressure coefficient for embedded soils and rocks
- Seismic earth pressure diagram and seismic earth pressure coefficient
- Steady-state water pressure distribution
- Soil spring parameters such as p-y curves (AASHTO 11.8.6.4) if soil structure interaction analysis is performed by the structure designer

<u>Recommendations</u>

- Minimum pile embedment below design grade for required geotechnical axial capacity, global stability, and basal heave stability
- Length of anchor unbonded zone calculated under service limit state or extreme event limit state, whichever is longer.
- Minimum lagging or wall face embedment below finish grade for erosion, local stability, and global stability
- Recommended arching capability factor to consider 3-D pile failure mechanism for discrete pile elements embedded below the design grade.
- Recommended ground anchor inclinations.
- Drainage system details and specifications, if horizontal drains are recommended to intercept the flow at a distance well behind the wall