Conventional Retaining Walls

This module presents the Caltrans standard practice for the geotechnical investigation, design, and reporting for conventional retaining walls. Conventional retaining walls are rigid gravity and semi-gravity retaining walls as defined in AASHTO LRFD BDS Section 11.2. Conventional retaining walls are reinforced concrete walls in the shape of an "L" or inverted "T". Conventional retaining walls commonly used are Retaining Wall Types 1, 5, and 6 as detailed in the Caltrans Standard Plans and Caltrans Revised Standard Plans, and Retaining Wall Type 7 as detailed in the Caltrans Bridge Standard Detail Sheets. Conventional retaining walls are also any variation or modification of these retaining walls that may include piles, sound walls, barriers, or enlarged foundations.

Retaining wall types detailed in the Standard Plans are designed through a coordinated effort between the Geoprofessional and District Design Engineer; however, upon special arrangement, Structure Design may act in place of the District Design Engineer. Retaining Wall Type 7 and varied or modified Standard Plan retaining walls are designed through a coordinated effort between the Geoprofessional and Structure Design.

The Geoprofessional assists in all phases of project development as requested by District or Structure Design. This assistance may include research, preliminary retaining wall design, and type selection during the project planning or early design phase; field investigation, analyses, external retaining wall design, and design support during the project design phase; and construction support and possible retaining wall alterations due to project changes or unforeseen conditions discovered during the construction phase.

Conventional retaining walls are typically type selected during project planning or early design phases through the coordinated effort between the Geoprofessional and project development staff. A more formal type selection process may be conducted for some retaining walls, as may occur for complex projects or wall sites. In such cases, the type selection should be based on preliminary geotechnical reports addressing the retaining walls. A thorough discussion of retaining wall type selection may be found in Chapter 10 of the Federal Highway Administration Publication No. FHWA-NHI-07-071, *Earth Retaining Structures Reference Manual*.

Investigations

A geotechnical investigation must be conducted for all retaining walls. The goal of the geotechnical investigation for conventional retaining walls is to determine the distribution, properties, and behavior of the soil and rock that will affect retaining wall design and construction; the groundwater condition that will affect retaining wall design and construction; the distribution of unsuitable or weak materials requiring remedial measures; and the suitability of excavated soil to be used as embankment fill or structure backfill.

The geotechnical investigation must provide data to determine the:

- strength and settlement characteristics of foundation soils
- strength and weight of soils to be retained
- strength and unit weight of soils affecting slope stability
- corrosion potential of soils in contact with the retaining wall
- groundwater location
- qualitative assessment of groundwater seepage

Refer to the *Geotechnical Investigations* module for direction on performing a literature search. In some instances, the information obtained through the literature search and field mapping may be sufficient for retaining wall design. Examples of such instances are walls built in “layer cake” sedimentary strata where nearby borings exist for the same sedimentary units, or walls founded on rock with abundant rock exposures and where previous testing is adequate to sufficiently characterize the rock.

Develop an exploration plan considering site constraints and available resources and consider the uncertainty and risk of not drilling at a particular location. The Geoprofessional should:

- Obtain retaining wall layout and configuration as accurately as possible. Final wall layout and height may not be determined until late in the design phase.
- Perform a literature search. Gather all relevant information related to site geology, geologic hazards, subsurface conditions, and soil and rock engineering parameters.
- Perform geologic field mapping of the wall site. The mapping should be sufficient to generate geologic cross sections along the retaining wall alignment when combined with other terrain data.
- Develop a subsurface exploration and laboratory testing plan to augment information gathered through archive research and field mapping. Space exploratory borings, Cone Penetration Test (CPT) soundings, and/or drive holes at maximum intervals of 100 to 200 feet along the proposed wall alignment, with borings strategically positioned in front, behind, and directly on the retaining wall layout line. The number of borings necessary to delineate site conditions may be reduced or increased due to the value of pre-existing data, uniformity of site geology, and the quality of site-specific geologic mapping.
- Where shallow foundations are anticipated, advance the subsurface exploration to an appropriate depth, which should generally extend below the foundation to the deepest of:
    - 15 feet,
    - twice the height of the retaining wall,
    - 4 times the estimated footing width, or

- to the full depth of soft, loose, weak soils upon which wall stability, bearing resistance, and settlement is dependent

- Conduct Standard Penetration Test (SPT) at maximum depth intervals of 5 feet. Closer intervals of SPT testing should be considered within a depth of 2 times the footing width below the proposed bottom of footing (the zone of greatest bearing pressure), and where soil strength properties are anticipated to be soft or loose.
- Conduct consolidation testing of clay soils wherever settlement magnitude and rate are significant project considerations.
- Where deep foundations are anticipated, refer to either the *Driven Pile Foundations* module or the *CIDH Pile Foundations* module.
- Gather data to evaluate the stability of excavations and cut slopes that will influence design and construction of the retaining wall. All material within the active wedge (i.e., retained zone) must meet the minimum strength assumed for structure backfill (friction angle, $\Phi = 34$ degrees).
- Estimate soil strengths based on index properties established through SPT, pocket penetrometer, torvane, and CPT (see *Soil Correlations* module). For retaining walls founded on Intermediate Geo Materials (IGM) or rock, strengths may be sufficiently estimated by reviewing data developed for similar rock on nearby projects. Perform laboratory strength tests only when correlation-based strengths result in borderline acceptable or unacceptable calculation results.
- Conduct corrosion testing on representative samples of the soil that will contact the retaining wall. Evaluate and interpret the collected data to arrive at reasonable assessments of corrosion potential. For example, if some samples gathered from a single sedimentary stratum or formational unit are found to be corrosive and other samples are found to be non-corrosive, the entire sedimentary stratum or formational unit should be deemed corrosive. If only a small zone of a formational unit appears to be corrosive, attempt to ascertain why only that zone should be regarded as corrosive.

- Sample and test mandatory borrow sites to determine if the material satisfies corrosion and gradation criteria for structure backfill. Sample and test project cut excavations to determine if material generated on-site will meet structure backfill requirements and should be designated for use as such. Conventional retaining walls may be constructed atop fills that do not exist at the time of the investigation but will be placed during the project. If the material borrow site is known the site should be investigated to determine soil properties useful in further evaluations.

Design

The design must address strength, service, and extreme event limit states.

The walls in the Standard Plan and Bridge Standard Detail sheets (known as XS sheets) have been designed for sliding, deflection, eccentricity and internal structural stability requirements for the specific retained soil strength listed on the plan sheets. The Geoprofessional must evaluate the site soil to determine if the conditions meet the minimum strength and stability criteria provided on the Standard Plan and the XS sheets.

The geotechnical design of a conventional retaining wall must include consideration of:

a. The design soil/rock profile
b. Factored Gross Nominal Bearing Resistances (Strength and Extreme Event Limit States)
c. Frictional resistance of foundation material for sliding analysis
d. Total and differential settlement
e. Overall slope stability (Service and Extreme Event Limit States)
f. Erosion susceptibility and mitigation
g. Seismic stability
h. Surface and subsurface drainage systems
i. Foundation improvement requirements
j. The minimum unbonded ground anchor length for Type 7 walls that incorporate ground anchors

Design Soil Profile

Use the geologic information to develop initial design soil profile(s) along the wall layout line, which may be revised to reflect ground improvement in the case that the design parameters are not met. See the *Reporting* section for a tabular presentation.

Design Parameters for Standard Plan Walls and XS Sheet Walls with Sound Walls

The following tables present the minimum foundation soil effective friction angle (phi) for all standard plan and XS sheet wall types, cases, heights, and limit states for bearing, sliding, and settlement (items b, c, and d above). The values represent the minimum required effective friction angle for all foundation materials in the bearing and settlement zone per the following:

For a given wall type, case, and height:

- The bearing influence zone is the foundation material that lies between the bottom of the footing and the depth of 1.5 times the effective footing width below the footing base.
- The settlement influence zone is the foundation material that lies between the bottom of the footing and the depth of 3 times the effective footing width below the footing base.
- Calculated settlement is 2 inches.
- All requirements of the Standard Plans and XS sheets (e.g., level ground in front of wall) must be met.

For example, the foundation material in the bearing stratum as defined in the preceding bullets must have Φ' = 34 degrees (or greater) for a 12-foot high Standard Type 1 (Case 2) retaining wall. If the requirement is met then the Geoprofessional must verify the design for items e, f, g, and h above prior to approving the wall design. If the requirement is not met, the wall does not meet the required standard plan design and cannot be used without ground improvement.

Minimum Effective Friction Angle for Standard Plan Walls

	Standard Type 1			Standard Type 1A		Standard Type 5		
Height (feet)	**Case 1**	**Case 2**	**Case 3**	**Case 1**	**Case 2**	**Case 1**	**Case 2**	**Case 3**
4	29	29	29	29	29	33	32	30
6	29	31	29	30	30	32	32	32
8	30	32	31	31	32	33	34	34
10	32	32	32	32	32	34	35	35
12	33	34	34	33	33	35	36	36
14	34	35	35					
16	35	36	36					
18	35	37	36					
20	36	38	37					
22	37	39	38					
24	38	39	38					
26	38	40	39					
28	39	40	39					
30	39	41	39					
32	40	41	40					
34	40	41	40					
36	40	42	40					

Minimum Effective Friction Angle for Standard Plan Walls (continued)

	Standard Type 6A		Standard Type 6B	
Height (feet)	**Case 1**	**Case 2**	**Case 1**	**Case 2**
3.33	29	33	29	33
4	29	33	29	33
4.67	29	33	29	33
5.33	29	33	29	33
6	29	33	29	33

Minimum Effective Friction Angle for XS Sheet Walls with Sound Walls

Height (feet)	Standard Wall Type 1 SW	Standard Wall Type 1 SWB	Standard Wall Type 5 SW	Standard Wall Type 5 SWB
6	29	29	32	32
8	31	31	33	33
10	32	32	34	34
12	34	34	34	34
14	36	36	35	35
16	34	34	36	36
18	35	35	36	36
20	36	36	38	38
22	36	36	38	38
24	36	36	38	38
26	37	37		
28	38	38		
30	38	38		
32	39	39		

Factored Gross Nominal Bearing Resistance (Strength and Extreme Event Limit States)

The Factored Gross Nominal Bearing Resistance must be calculated for soil foundations for both the Strength Limit State and Extreme Limit State. The bearing resistance is affected when groundwater is at a depth less than 1.5 times the footing width below the footing base. Determine the bearing resistance using the highest anticipated groundwater level at the footing location according to AASHTO LRFD BDS Section 10.6.3.

For bearing resistance on rock follow the design procedures in AASHTO LRFD BDS Section 10.6.3.2.

Walls on Slopes

The proximity of a retaining wall footing to a descending slope must be considered in the bearing resistance calculations. If the finished ground in front of the retaining wall slopes downward within a distance that is twice the width of the footing measured from the retaining wall toe, then the bearing resistance will differ from the level ground configuration.

The Modified Bearing Capacity Factors for Footing Adjacent to Sloping Ground (AASHTO LRFD BDS 10.6.3.1.2c) developed by Meyerhof (1957), or similar, must be used. Table C11.10.2.2.1 in the AASHTO LRFD Bridge Design Specifications provides guidelines for minimum foundation embedment when a wall is located on a slope.

Additionally, a sliding analysis using the retaining wall configuration, the foundation soil characteristics, and the slope geometry must be conducted. Because the site geometry does not conform to the Standard Plans and Standard Details, the PS&E must be prepared by Structure Design. The sliding analysis will be performed by the Structure Designer. The Structure Designer may request assistance from Geotechnical Services with calculating the factored sliding resistance. See AASHTO LRFD BDS section 10.6.3.4.

Settlement Evaluation (Service Limit State)

Calculate settlement using the net bearing stress shown in the Standard Plans, Revised Standard Plans, XS Sheets, or provided by the Structure Designer. If the calculated settlement is less than or equal to the specified permissible settlement, the retaining wall geometry and configuration meet the Service Limit State settlement criteria. If the calculated settlement exceeds the permissible settlement, then the retaining wall must be redesigned or the foundation conditions improved.

Settlement must be calculated per AASHTO LRFD BDS Section 10.6.2.4. The total settlement may include elastic, consolidation, and secondary components. Settlements must be within the tolerable criteria for the type of retaining wall selected. The settlement must be calculated for the Service Limit State stress. The settlement evaluation must include settlement that occurs during and after wall construction.

Tolerable total and differential settlement criteria are as follows:

Wall Type	Tolerable Total Settlement	Differential Settlement over a Distance of 100 feet
Conventional Retaining Wall	≤ 2”	≤ 0.75”

More stringent tolerances may be necessary to meet aesthetic requirements for the walls.

Settlement evaluation for foundations on rock must follow the recommendations in AASHTO LRFD BDS Section 10.6.2.4.4.

Foundation stress distribution that may affect known underground utilities or adjacent structures must be evaluated. Results should be shared with the client so that the appropriate stakeholder is consulted.

Sliding Evaluation

Sliding evaluation is the responsibility of the Structure Designer. The Structure Designer may request assistance calculating the factored sliding resistance.

Overall Slope Stability (Service and Extreme Event Limit States)

The overall stability of the wall must be calculated using Service I Loads and AASHTO LRFD BDS Section 11.6.2.3.

Erosion Susceptibility and Mitigation

Embedment of the retaining wall foundation must account for anticipated scour, erosion, or undermining. AASHTO LRFD BDS Sections 2.6.4.4.2 and 10.6.1.2 must be followed. Considerations for embedment should include slope geometry, erosional potential in front of the wall, frost heave protection, future construction activities, and external and global wall stability.

When the foundation material is subject to erosion or scour, measures must be taken to avoid undermining. In this instance the embedment may exceed the minimum embedment depth requirements, and additional countermeasures such as erosion control and hard facing should be considered.

The minimum cover for a conventional retaining wall footing is 1.0 or 2 feet.

Seismic Stability

Standard Plan Retaining Wall site seismic criteria threshold must be analyzed to confirm that the Coefficient of Horizontal Acceleration, k_h does not exceed 0.2. The k_h is calculated as 1/3 Horizontal Peak Ground Acceleration (HPGA). Therefore, at sites where the HPGA is equal to or less than 0.6g the Standard Plans are applicable. At sites where the HPGA is greater than 0.6g the wall will require seismic displacement analyses in accordance with the *Geotechnical Seismic Design of Earth Retaining Systems* module.

Seismic recommendations must also address seismic hazards such as liquefaction impacts to bearing resistance, overall stability, and lateral deflection. The maximum allowable displacements are governed by wall performance and potentially impacted facilities.

Surface and Subsurface Drainage Systems

Additional drainage measures should be implemented if the wall backfill cannot be depended on to be fully drained or if the groundwater conditions at the project site will affect the integrity of the wall. These additional groundwater control measures may include standard or deep underdrains and horizontal drains in addition to geocomposite drains, and drainage blankets at the wall or at the back of the backfill. To the greatest extent possible these groundwater control measures should prevent the infiltration of groundwater into the structure backfill. If wall drainage cannot be relied upon, the wall must be designed for hydrostatic pressure.

Surface drainage should be directed away from the wall. If this is not possible, surface drainage appurtenances such as impervious drainage inlets, lined ditches, curbs and gutters should be recommended.

Infiltration basins should not be positioned to introduce water into the retained earth zone or into the foundation material. The effects of bioswales on earth retention systems should be carefully considered. Depending upon the details of their construction, bioswales may lead to increased infiltration of water, and the possibility of increased hydrostatic pressure and pore pressures.

Modified Design of Conventional Retaining Walls

Review the proposed retaining wall configuration for conformance with the Standard Plans and XS Sheets. Among the important configuration elements to check are the lateral distance to a descending slope in front of the retaining wall, the vertical footing cover, the ground slope in the retained zone, additional surcharges that deviate from the live traffic loading, and the HPGA. For configurations other than those shown in the Standard Plans, special design walls by Structure Design are required.

For the modified design of Standard Plan and XS Sheet retaining walls the Structure Designer will evaluate the lateral sliding and deflection, eccentricity of the resultant foundation load, and internal structural stability requirements.

When the lateral earth pressures resulting from surcharge loads do not conform to those assumed for the Standard Plans and XS Sheets, project specific lateral earth pressures must be developed based on Section 3.11.6 of the AASHTO LRFD Specifications.

Retaining Walls Supported on Piles (Type 1, Type 5 and Type 7)

Pile tip elevations for the Strength, Service and Extreme Load demand must be determined according to the applicable deep foundations module. Factored pile load demands will be provided by the Structure Designer and determined on a project specific basis.

Bridge Design Detail Sheets are available for Type 1 SWP, Type 1 SWBP, Type 5 SWP, Type 5 SWBP, Type 7 SWP and Type 7 SWBP. These sheets show the use of driven Class 90 battered piles. Where battered piles are used, a portion of the lateral demand on the foundation piles will be resisted by compression of the battered piles.

When vertical piles are required, site specific lateral pile analyses are required. The Geoprofessional may be requested to provide the Structure Designer with foundation soil parameters to perform the analysis.

Type 7 Retaining Walls with Ground Anchors

Type 7 Retaining Walls use ground anchors to resist overturning, sliding, and/or uplift. The anchor bond zone must be developed below the theoretical shear failure zone for bearing resistance. There is typically at least 5 feet between the bonded zone and the theoretical shear failure surface in the foundation soil or rock. Use a minimum ground anchor unbonded length of 15 feet. The minimum horizontal spacing of anchors should be greater than 3 times drilled hold diameter to minimize group effect between adjacent ground anchors.

Ground Improvement

Where existing foundation materials do not provide adequate bearing resistance or result in excessive settlement, consider improving the foundation conditions by removing some or all of the unsuitable material, and replacing it with compacted fill. Material meeting the specification for structure backfill or aggregate base is often used as the replacement material. Consideration should be given to whether a geotechnical fabric is required to separate the backfill from the native soils or to enhance the subgrade behavior. Standard Specification Section 19-5.03B discusses a typical configuration that could be used for removal and replacement. Recommend that a typical section for the “remove and replace” be provided in the plans.

Where "remove and replace" is not feasible, consider ground improvement options as an alternative to deep foundations (see *Ground Improvement* module).

Although lightweight fill such as cellular concrete, expanded polystyrene (EPS) blocks and volcanic materials (Scoria) may not be considered as ground improvement, they can be used as backfill material behind the conventional retaining wall to reduce the active pressure and to decrease the foundation stresses.

Reporting

Present Standard Plan retaining wall recommendations in a Geotechnical Design Report. Include the following:

1. Date of plan (e.g., Retaining Wall Layout Sheet) used for design
2. Description of the recommended standard plan wall
    a. Wall Type
    b. Location (begin and end station, length, and alignment)
    c. Design Height (maximum and minimum)
3. Geotechnical design parameters
    a. Design Soil/Rock Parameters table
    b. Ground water surface elevation
    c. Ground line condition and load case(s)

Design Soil/Rock Parameters

Layer No.	Layer boundaries	Group Name	Engineering Parameters
1	Finished grade to elev. 300	Silty Sand (fill)	Φ = 34 degrees, γ = 120 pcf
2	Elev. 285 to 300	Silty Sand	Φ = 33 degrees, γ = 113 pcf
3	Elev. 272 to 285	Poorly Graded Sand	Φ = 34 degrees, γ = 120 pcf
4	Elev. 250 to 272	Granite	Qu = 5000 psf, γ = 150 pcf

Conventional retaining wall recommendations prepared for Structures Design must comply with the *Foundation Reports for Earth Retaining Systems* module.

- If the conventional retaining wall is connected to a bridge, include the retaining wall recommendations in the foundation report for the bridge.

- All other conventional retaining walls prepared for Structure Design must be reported in its own foundation report.

References

1. AASHTO LRFD Bridge Design Specifications, (Eighth Edition) with California Amendments
2. Caltrans Standard Plans and Revised Standard Plans
3. Caltrans Memo to Designers (MTD) 5-19, *Earth Retaining Systems Communication*
4. Caltrans Memo to Designers (MTD) 5-5, *Design Criteria of Standard Earth Retaining Systems*
5. Caltrans Bridge Design Details 1-16*, Use of Bridge Standard Detail Sheets (XS-Sheets)*
6. Caltrans Bridge Design Aids (BDA) 3-7, *Pile Layouts for Standard Plan Retaining Wall*s
7. Federal Highway Administration Publication No. FHWA-NHI-07-071, *Earth Retaining Structures Reference Manual,* June 2008.
8. Federal Highway Administration Publication No. FHWA-IF-99-015, Geotechnical Engineering Circular No. 4, *Ground Anchors and Anchored Systems*, June 1999.