Below Grade Structures

This module presents the Department's standard of practice for the investigation, design, and reporting of Below Grade Structures. Below Grade Structures (BGS) are those that will be either partially or entirely buried and will experience significant loading from lateral earth pressures or vertical pressures from fill placement above the structure. Offices that may request BGS recommendations from GS are listed in Table 1.

Table 1: Below Grade Structures and Requesting Offices

Below Grade Structure	Typical Requesting Office
Weigh Station Pits	District Design, Transportation Architecture, Bridge Design
Pump Plants	Bridge Design, District Design, Transportation Architecture
Culverts	District Design, Hydraulics
Buried Bridges and Walls	Bridge Design
Underground Water Storage Boxes	District Design, Transportation Architecture
Infiltration Structures	District Design

Design of BGS will typically require special design. However, in certain instances, such as drainage inlet structures, box culvert drainage systems, and pipe culvert walls, standard plan design may be used if ground conditions meet the loading demands noted on the Standard Plan Sheets (D72-73, D80-86, D89 - D90, respectively). For more information on the intent and procedures for standardized designs using Standard Plan sheets, refer to the *Geotechnical Design using Standard Plan and Bridge Standard Detail Sheets* Module.

The Geoprofessional (GP) assists in all phases of project development as requested by the coordinating Office responsible for design of the BGS. This assistance may include research, preliminary design, and type selection during the project planning or early design phase; field investigation, analyses, design support during the project design phase; construction support and design alterations due to project changes or unforeseen conditions discovered during the construction phase.

Investigations

Projects involving BGS often require a site-specific geotechnical investigation. The GP is responsible for characterizing the soil, rock, and groundwater as well as the extent to which any unfavorable conditions or poor soils exist at the project site. Refer to the *Geotechnical Investigations* module for general instructions on performing the planning-phase site investigation (e.g., literature review, site visit) and the design-phase site investigation (e.g., site visit, selection of investigative methods, locations, and depths).

The geotechnical investigation must consider the required deliverables. To meet these deliverables, the data collected in the field and lab should be prescribed to aid the necessary analysis, reporting, and construction recommendations including:

- strength and settlement (elastic, consolidation) characteristics of foundation soils
- determination of appropriate foundation (standard vs special design, shallow vs deep foundations)
- strength and weight of soils to be retained
- lateral and vertical earth pressures
- groundwater
- uplift pressures
- permeability and infiltration rates
- excavation and caving Issues
- liquefaction assessment (settlement and potential uplift/flotation)
- corrosion potential of soils/water in contact with the structure

Investigation programs can vary widely depending on the structure type. For example, a buried bridge (i.e., a conventional bridge that is subsequently buried for creation of a wildlife crossing habitat), may require multiple borings at each support. Alternatively, for other BGS such as infiltration structures, it may be sufficient to perform hand auger borings in conjunction with in-situ infiltration testing. The GP should consider the required design, loading, and anticipated ground conditions when planning investigation techniques, as well as sampling types and intervals. For larger projects such as buried bridges it may be necessary to collect undisturbed samples for consolidation and triaxial strength testing. If loose saturated sand deposits exist below the foundation, it may be prudent to decrease the spacing in between SPT samples or perform additional CPTs. For pump plants, samples may be collected for permeability testing. For smaller, conventional projects, design using correlations may be sufficient (see the *Soil Correlations* module).

Conventional drainage systems, such as buried HDPE or pre-cast concrete pipes, which rely on cut and cover methods often do not require site specific investigation. Additionally, where sufficient As-Built data exists at a site, there may not be a need for new subsurface investigation.

Refer to the *Geotechnical Investigations* module for additional guidance regarding investigations as well as other modules applicable to the structure and foundation type. Additional guidance on planning investigations, quantities of borings, and sampling depths/intervals can be found in AASHTO LRFD Bridge Design Specifications Table 10.4.2-1 and California Building Code (CBC) Section 1803.

Design Standards

Applicable design standards will vary by project type. A general summary for guidance is presented in Table 2, however, each project may require special consideration.

Table 2: Below Grade Structures Applicable Design Guidance and Standards

Below Grade Structure	Applicable Design Standards and Guidance						
	AASHTO LRFD	CBC	CT Seismic Design Criteria	Standard Plan Design	Special Design	Caltrans Corrosion Guidelines	Applicable MTDs
Weigh Station Pits[1]	--	X	--	--	X	X	Section 4
Pump Plants	X[4]	X[4]	X[4]	--	X	X	Section 3 and 4, 5-5, 5-12, 5-19, 20-10, 20-15
Culverts	X	--	X[2]	X	X	X	Section 3 and 4, 20-10, 23-1
Buried Bridges and Walls	X	--	X	--	X	X	1-29, Section 3 and 4, 5-1, 5-2, 5-5 5-12, 5-19, 20-1, 20-10, 20-15
Underground Water Storage Boxes	X[4]	X[4]	X[4]	X[3]	X	X	Section 4, 20-10, 23-1
Infiltration Structures	X	--	X[2]	--	X	X	Section 4, 23-1

Notes:

1. *Weigh station projects may often involve other project components such as multi-platform scales and inspection canopies. While the weigh station design utilizes CBC design, other project components may utilize AASHTO-CA-BDS and Seismic Design Criteria.*
2. *Infiltration Structures and Pipe culverts are not designed for seismic events.*
3. *Underground Water Storage Boxes may utilize Standard Plan Design (e.g., Box Culverts).*
4. *Most pump plants and underground water storage boxes are designed per the CBC. However, where standard plan box culverts are used or the use of pile foundations are required, refer to AASHTO-CA-BDS and the applicable module(s).*

<u>Design Parameters and Analyses</u>

Analyses for BGS will depend on the specific structure, loading, and foundation type, as well as ground conditions at the site. Design considerations will often involve more than just foundation loading and may require assessment of other important geotechnical related issues such as settlement and lateral earth pressures as well as groundwater related parameters such as permeability. The GP should ensure that any potential for volume change (consolidation or expansion) are properly quantified and mitigated appropriately. Expansive soils can result in lateral pressures well beyond normal active or at-rest conditions on BGS walls and have the potential to heave BGS slabs-on-grade.

A summary of typically required parameters and analyses are shown in Table 3.

Depending on the complexity of the project, analysis may be in the form of a simplified calculation, spreadsheet, computer software or may require specialized finite element analysis such as in cases with sensitive excavation stability, seepage issues, or interaction amongst multiple project components. Initial results may dictate that additional analysis is required. For example, on projects where structures may be adjacent to ascending slopes, earth pressures on BGS walls may require that additional ground support systems such as ground anchors or tie backs are necessary. For projects with unique geometry, conventional Rankine or Coulomb type analysis may not properly quantify earth pressures. In such instances it may be appropriate to use the Generalized Limit Equilibrium (GLE) method to calculate earth pressures.

Table 3: Typical Below Grade Structures Design Parameters and Analyses

Below Grade Structure	**Data / Parameters**[1]							**Analyses**[1]										
	Index / Soil Classification	**Groundwater**	**Soil Strength (c/phi, S_u)**	**Consolidation**	**Expansion Potential (EI, SE)**	**Permeability / Infiltration Rate**	**Corrosivity**	**Aquifer Conditions**	**Dewatering**	**Excavation Stability**	**Buoyancy Effect (Uplift)**	**Seismic Parameters**	**Liquefaction**	**Seismic Displacement / Lateral Spread**	**Foundation Design**	**Settlement**	**Lateral Earth Pressures**	**Global Stability**
Weigh Station Pits	T	T	T	C	C	N	T	N	N	C	N	T	C	C	T	C	T	N
Pump Plants	T	T	T	T	C	T	T	C	C	T	C	T	T	T	T	T	T	C
Culverts	T	T	T	C	C	C	T	N	C	C	C	T	C	T	T	T	T	C
Buried Bridges	T	T	T	T	C	N	T	N	C	C	N	T	T	T	T	T	T	C
Underground Water Storage Boxes	T	T	T	N	C	C	T	N	N	C	C	C	C	C	C	C	T	C
Infiltration Structures	T	T	T	N	C	T	T	C	N	C	C	C	C	C	T	C	C	C

Notes:

1. *T = Typical, C = Consider depending on structure/ground conditions, N = Not Typical*

Because required design parameters and analyses vary by structure type, refer to the applicable module(s) listed below.

- Soil Correlations: Estimating shear strength, friction angle and unit weight from SPT blow counts.
- Corrosion Evaluation: Applicable to all Below Grade Structures.
- Standard Plan Designs: Guidance on Below Grade Structures that use standard plan design, such as Reinforced Box Culverts.
- Geotechnical Design Parameters: Applicable for preparing soil profiles for use in design on most Below Grade Structures.
- Design Acceleration Response Spectrum: Applicable to all Below Grade Structures utilizing Caltrans Seismic Design Criteria.
- Faut Rupture: Module to be utilized when a Below Grade Structure site is located on a fault or a fault crossing.
- Liquefaction Evaluation: Provides guidance on performing liquefaction evaluation at sites with potentially liquefiable soils.
- Lateral Spreading: Utilized when a Below Grade Structure is located at a liquefiable site with sloping ground.
- Earth Retaining Systems: Provide design guidance for below grade walls or buried bridges, pump plants, etc.
- Structure Foundations: Multiple Structure Foundations modules provide guidance for design and analysis of the applicable foundation type. For example, a buried bridge project may reference the Bridge Foundation Selection, Driven Pile Foundations, CIDH Pile Foundations, or Downdrag Modules.
- Bridge Foundation Selection: Useful guidance on selection of shallow versus deep foundation types and alternatives.
- Stormwater and Wastewater BMPS: Reference on infiltration structures.

More guidance on selection of design parameters and analyses for BGS as well as appropriate resistance factors may be found in the following sources:

- AASHTO-CA-BDS, Section 10 – Foundation Design
- AASHTO-CA-BDS, Section 11 – Walls, Abutments, and Piers (including guidance on design of passive, active, and seismic earth pressures).
- AASHTO-CA-BDS, Section 12 – Buried Structures

For BGS utilizing the California Building Code, guidance may be found in Chapter 18 – Soils and Foundations.

BGS In Contact with Groundwater

BGS in contact with the groundwater table require special considerations and are most common on projects involving pump plants. Because pump plants are generally located at topographic low points and specifically constructed to remove water from a site, groundwater will often be encountered during construction. Additionally, these sites are often located in areas with contaminated groundwater, such as along the state roadway system or nearby ports and harbors. The Geotechnical Archive (GeoDOG), District databases and state groundwater databases should be reviewed during the preliminary project phase for historic data and to provide applicable concepts for design and construction strategies. Projects featuring BGS in contact with groundwater require extra collaboration between DES and the District functional units. It is important to consider groundwater impacts throughout project development, project construction, and design life of the BGS; and to ensure effective communication with the project development team.

All available techniques for construction below groundwater should be considered during the planning and design phases of the project. These include ground improvement, dewatering, and constructing in the wet (such as with a slurry head). Seepage analysis and any proposed dewatering require special caution. Dewatering should be promoted only for nuisance seepage and not for drawdown as an engineering or construction solution given the prohibitive costs of handling groundwater. Pumping of contaminated groundwater requires special handling requirements and therefore should be prohibited in all design and construction solutions.

In coordination with our clients and partners, the GP may need to perform rigorous investigation, testing, or advanced modeling should complex groundwater conditions exist. The actual scope or magnitude of investigations and analyses should be related to the complexity of the site and the project. Field investigations may need to involve developing exploratory boreholes as groundwater monitoring wells for slug testing or pump testing.

For BGS projects that potentially involve pumping, it is important to have a good understanding of the hydraulic conductivity of the site. Hydraulic conductivity is the primary parameter governing flow through a dewatering system. This parameter can be estimated from published data (soil gradation), field testing, lab permeability testing, and software programs. Field testing may involve pump testing or slug testing. A slug test is a relatively cost-effective and efficient way to estimate hydraulic conductivity. The solid-slug test is conducted by quickly lowering or removing an object of known volume (i.e., the slug) in or out of a water column within a well that is screened within the seepage zone of concern, causing the water level inside the well to rise or fall, respectively. The water level is monitored and recorded over time until it returns to equilibrium. The response and recovery of the aquifer may be used to estimate the hydraulic conductivity. Numerous methods are available for analysis of slug data (e.g., Bouwer-Rice (1976), Cooper (1967), and Horslev (1951), amongst others).

Reporting

Table 4 lists the applicable reporting standard to be used for each type of BGS.

Table 4: Reporting Standards for Below Grade Structures

Below Grade Structure	Reporting Standard
Weigh Station Pits	Foundation Reports for Buildings and Miscellaneous Structures
Pump Plants	Foundation Reports for Buildings and Miscellaneous Structures
Culverts	Geotechnical Design Reports
Buried Bridges	Foundation Reports for Bridges
Buried Walls	Foundation Reports for Earth Retaining Systems
Underground Water Storage Boxes	Foundation Reports for Buildings and Miscellaneous Structures
Infiltration Structures	Geotechnical Design Reports