Building and Miscellaneous Structure Foundations

This module presents the Department's standard of practice for investigation and design of buildings and miscellaneous structures. Structures that may require design support from GS include buildings, retaining walls, canopies, tanks, power generation equipment, and lighting. The Office of Transportation Architecture (OTA) prepares the plans and specifications for buildings and miscellaneous structures and this module addresses geotechnical practice that is specific to OTA designed facilities.

The structures addressed in this document are designed in accordance with the *California Building Code* (CBC) and *ASCE 7*.

Buildings and miscellaneous structures are most often funded from the Minor A or B Program. As a result, the foundation investigation, design, and reporting generally occur at the design or 1-phase of a project (WBS 240.80). Preliminary design work in the K or 0-phase happens infrequently.

Most buildings and miscellaneous structures are founded on shallow foundations (i.e., spread footings, continuous footings). While the CBC provides *Presumptive Load Bearing Values* in Table 1806.2, Caltrans practice is to perform a site investigation and compute the allowable bearing pressure and foundation settlement at each structure location. Exception: The *Presumptive Load-Bearing Values* table *(Vertical Foundation Pressures)* may be used at sites where rock is present at the bottom of footing elevation.

Deep foundations are less economical and should only be used after all shallow foundation options are exhausted.

Investigations

As the total construction cost of transportation buildings and miscellaneous structures is relatively small when compared to bridges, the investigation plan should be scrutinized and limited to acquire only the information that is essential to complete the design.

The investigation for a building foundation seeks to identify and characterize the subsurface material, determine material strength parameters, locate the water table (if within a depth that would affect the foundation design), and to identify conditions that might affect the foundation construction or performance, such as the presence of boulders, shallow rock, liquefiable, collapsible, or expansive soil.

The investigation should include at least one borehole/CPT per building and 10,000 square feet of building and/or structure footprint, unless there is reason to believe the geology varies. Where shallow foundations are anticipated, investigative depths should extend to a depth necessary to evaluate bearing, settlement, and liquefaction. If deep foundations are anticipated, refer to the *Driven Pile Foundations* module or the *Cast-In-Drilled-Hole Pile Foundation* module for guidance on investigations.

Perform drilling using hollow stem augers so that groundwater observations can be made. Once groundwater is encountered, switch from auger to mud rotary.

Perform SPT sampling at 2.5-foot intervals to a depth of 15 feet below the bottom of the footings. Perform field pocket penetrometer or torvane tests on cohesive soils. Perform corrosion testing on the soil and groundwater that will be in contact with foundation elements.

Use the *Soil Correlations* module to determine soil strength and unit weight. Presenting the "soil identification" as determined by the *Soil and Rock Logging, Classification and Presentation Manual* is sufficient. Consider performing laboratory strength tests only when the field test results are limited or in question. Perform additional tests to evaluate conditions such as consolidation, collapse, or expansion, if required for analyses.

Test pits or potholes may be used only to verify material type when using the *Presumptive Load Bearing Values* in rock.

Seismic Information

Seismic design and site seismicity are determined per CBC Section 1613, which utilizes ASCE 7, *Minimum Design Loads and Associated Criteria for Buildings and Other Structures*. The seismic parameters are determined per CBC Sections 1613.2 and are presented in the following steps.

Step 1: Determine the Site Classification

Per Section 1613.2.2 of the CBC, determine the Site Class in accordance with ASCE 7, Chapter 20.

Note: If a default Site Class D is selected (in cases where site-specific data is not available) there is a required increase in the spectral acceleration that may impact the building design and cost.

Step 2: Determine Spectral Accelerations

CBC Section 1613.2.1 can be used to determine the 0.2 second or short period (S_S), and 1 second period (S_1) spectral accelerations. However, for most locations in California, the CBC figures are not of sufficient clarity to determine the S_S and S_1 coefficients. Use the URL below to access the California Office of Statewide Health Planning and Development (OSHPD) website to determine S_S and S_1. While this website does calculate the seismic parameters, they should be verified by hand calculations following the methods provided in CBC Sections 1613.2.3 and 1613.2.4.

https://seismicmaps.org/

The calculator on the website requires that the project location be entered either by coordinates or by locating the project location on a map. Enter the appropriate design code reference document. This is tied to the version of the CBC that OTA is using for design of the structure. Use Risk Category II for occupied maintenance structures as this is the category applies to residential, commercial, and industrial buildings. For other structures, discuss with OTA to determine the appropriate Risk Category.

Seismic Hazards

Evaluate the following seismic hazards:

a. Surface fault rupture (see CBC 1803A.2, CBC 1803A.6, and *Fault Rupture* module)
b. Liquefaction (see CBC 1803.5.11 and *Liquefaction Evaluation* module)
c. Effects of Liquefaction, including
    i. Seismically-induced ground surface settlements
    ii. Lateral spreading (see *Lateral Spreading* module)
d. Seismic slope stability
e. Tsunami risk

Design

Building and miscellaneous structure foundations are designed per CBC Chapter 18 and using the Allowable Stress Design methodology.

Spread Footings and Continuous Footings

Compute the ultimate bearing pressure (i.e., gross nominal bearing resistance in LRFD) following the analytical methods provided in the *Shallow Foundations for Bridges* module. Compute the allowable bearing pressure by applying a Factor of Safety of 3 to the ultimate bearing pressure.

The following design requirements also apply:

- The CBC Section 1809.4 specifies the minimum embedment into undisturbed material must be 12 inches. Bearing resistance, frost penetration and erosion considerations influence this recommendation.
- The CBC Section 1809.4 specifies the minimum footing width must be 12 inches.
- Per CBC Section 1809.5, unless founded on rock, footings are either founded at depths below frost penetration or are constructed in compliance with ASCE 32. Frost depth is determined by consulting the local building codes. Knowledge of frost depth from local practice at the project site are the best sources of information. In general, penetration of frost into the ground is a potential design factor in higher elevations of mountainous areas (FHWA NHI-01-023, *Shallow Foundations*, Section 2.5.1). Conditions for the exception to this specification are found in CBC Section 1809.5.

- The presence of expansive soil beneath footings should be investigated and analyzed. Building footings are relatively lightly loaded and may be susceptible to damage caused by expanding and contracting foundation soils. If evaluation of the uplift pressure indicates that it exceeds the contact stress resulting from the service loads on the footings, mitigation should be considered. The first strategy that should be considered is to remove-and-replace the expansive soil or treatment-in-place to eliminate the expansion potential.

The allowable soil pressure for certain materials may be increased by 33% for load combinations that include short term or transient loads used in the alternative basic load combinations of Section 1605.2.

Perform total and differential settlement calculations for building structures following the methods in the *Shallow Foundations for Bridges* module. Perform settlement calculations using the Allowable Load.

Lateral load demands on footings are resisted by a combination of friction along the bottom of the footings and lateral passive bearing pressure along footing vertical surfaces. Determine the coefficient of friction for sliding of the foundation along subgrade soils per Section 1806.3. The coefficient of friction values provided in Table 1806.2 are presumptive and may be exceeded if data from a field investigation supports doing so. Also consult Section 3.10.1 of FHWA NHI-01-023, *Shallow Foundations* for guidance to determine the lateral sliding resistance.

Determine the presumptive lateral bearing pressure per CBC Table 1806.2. Check the presumptive passive lateral earth pressures using Rankine earth pressure theory with a 50% reduction to account for excessive lateral movement.

<u>Deep Foundations</u>

Driven piles are rarely warranted for building foundations and CIDH piles are extremely rare. Building and canopy load demands are low and adequate bearing resistance is typically achieved with continuous (strip) or spread footings. Settlement behavior may warrant deep foundations, particularly when evaluating differential settlement with relationship to adjoining or connecting features with minimal foundation loads (e.g., utilities, walkways, driveways).

Perform the deep foundation design in accordance with the *Driven Pile Foundations* module or *CIDH Pile Foundations* module. However, deep foundations for buildings are designed utilizing the CBC which specifies the Allowable Stress Design methodology. The allowable bearing load or pile design load is determined by applying an appropriate Factor of Safety to the pile's ultimate capacity (i.e., nominal resistance in LFRD). CBC Section 1810.3.3.1.7 specifies that a minimum value of 2 is used for the Factor of Safety, and this should be discussed with OTA prior to finalizing the design.

Piles may be subject to lateral loads, particularly if they are not fully embedded. If the upper portions of piles are unbraced in air or water, or the upper portions of the piles are embedded in weak soils, the OTA designer may request assistance with a lateral pile analysis. Consult the CBC for lateral load and resistance requirements.

The foundation design must consider the effects of liquefaction and down drag.

Concrete Slabs on Grade

Determine the modulus of subgrade reaction for slab foundation soil by first determining the representative subgrade modulus (k) for a 12-inch plate load test using Table 4 (Lindeburg, Civil Engineering Reference manual, 15th Edition). Higher values within each range are appropriate for stiffer or denser soils.

Table 4: 12-inch Plate Subgrade Modulus

Group symbol	Range of subgrade modulus, k (psi/in)
GW	300-500
GP	250-400
GM	100-400
GC	100-300
SW	200-300
SP	200-300
SM	100-300
SM-SC	100-300
SC	100-300
ML	100-200
CL[1]	50-200
OL[1]	50-100
MH[1]	50-100
CH[1]	50-150
OH[1]	25-100

1 – Remove and replace with Structure Backfill create a uniform bearing surface and to increase the Subgrade Modulus.

Modify the k value to reflect the dimensions of the foundation on cohesionless soil to determine the modulus of subgrade reaction for slab foundation as follows:

- Square footings or floor slabs

$$ks = k\left[\left[\frac{B+1}{2B}\right]^2\right]$$

- Rectangular footings or floor slabs

$$ks\ rect = ks\left[\frac{1 + 0.5\left(\frac{B}{L}\right)}{1.5}\right]$$

- Continuous footings

$$ks\ cont = 0.67\ ks$$

Where:

B = the foundation width

L = the length of a rectangular foundation

If it's anticipated that moisture can reach the bottom of the floor slab, a vapor barrier should be recommended. OTA will specify the vapor barrier configuration and material type.

Determine if expansive soil exists beneath the planned slab(s) per CBC Section 1803.5.3. Soils having an expansion index greater than 20 as determined by ASTM D4829 are considered expansive. Collaborate with the Structure Designer to determine a course of action when expansive soil is present.

Floor slabs are lightly loaded and susceptible to damage caused by expanding and contracting foundation soils. If evaluation of the uplift pressure indicates that it exceeds the contact stress resulting from the dead weight of the slab, mitigation should be considered. The first strategy that should be considered is removal of the expansive soil and replacement with structure backfill, or chemical treatment to eliminate the expansion potential.

Retaining Walls and Earth Retaining Structures (ERS)

Retaining walls located in non-highway settings do not typically utilize the Standard Plan concrete cantilever retaining wall design details. The OTA designer will most often start with the standard plan wall concrete cantilever design as a template and modify the design with the intent of economizing. This is achieved by not designing the retaining wall for loads that are not applicable, such as traffic surcharges.

The OTA designer will request the *lateral soil loads*. Use Table 1610.1 of CBC Section 1610.1 to determine the *lateral soil load* (at-rest or active), whichever is applicable. The results of the geotechnical investigation can be also used to determine the *lateral soil load*. The values provided in Table 1610.1 apply to moist drained soils. If the retaining wall backfill is undrained, then the retaining wall is designed for hydrostatic pressure in addition to the submerged soil being retained. Refer to the applicable Geotechnical Manual module for investigation and design requirements.

Site Grading

Analyze the stability of the proposed cut and fill slopes in accordance with the applicable module(s). Evaluate settlement for locations where fill is to be placed. Recommendations for settlement periods should be the priority mitigation measure to address unacceptable settlement and differential settlement. Fill surcharge may be considered in rare cases.

Assess suitability of on-site materials for use as structure backfill.

Radio Communications Towers and Infrastructure

The equipment for radio communications is purchased as a package from the manufacturer and a prescriptive foundation design is included with the equipment. OTA will check the design of the foundation elements and may request that GS provide bearing resistances and lateral soil resistances. Compute passive lateral earth pressure distributions using Rankine Earth Pressure theory (see *Non-Gravity Cantilever Retaining Walls* module). Presumptive *lateral bearing pressure* values are provided in CBC Section 1806, Table 1806.2. Per Section 1806.3.4, the table values can be doubled for short-term loads if 0.5-inch displacements do not adversely affect performance or maintenance.

Reporting

Prepare a Foundation Report in accordance with the *Foundation Reports for Buildings and Miscellaneous Structures* module.

Produce a Log of Test Borings (LOTB) sheet, and/or As-built LOTB sheet (if any).