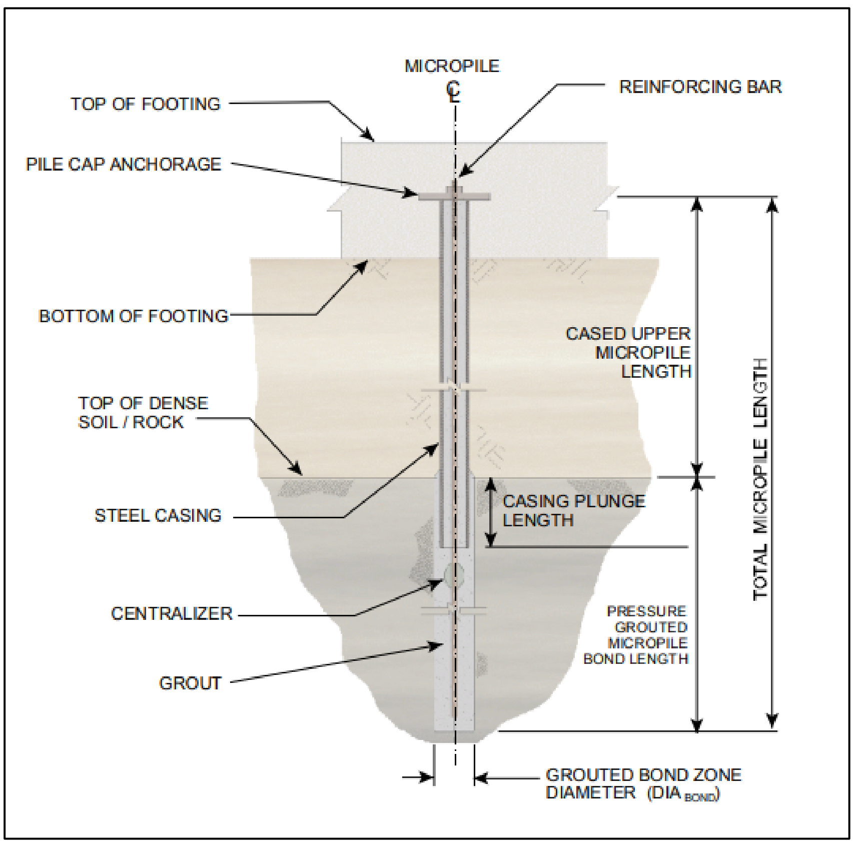
Micropiles for Structure Foundations (Category A Micropiles)

Micropiles are an option for use as foundation support elements or as in-situ reinforcements to provide stabilization of slopes and excavations. The intent of this module is to provide geotechnical design guidelines when micropiles are to be used as foundation support elements (**Category A** micropiles, as defined in the Micropile Classifications section of this module). The design of micropiles for slope stabilization (**Category L** micropiles) is not presented in this module.

A micropile is a relatively small diameter (typically less than 12 inches) grouted pile with internal reinforcement. A micropile is constructed by drilling a borehole (typically using temporary casing), placing steel reinforcement inside, and grouting the hole. Micropile reinforcement may consist of a single reinforcing bar, a group of reinforcing bars, and/or a steel casing. The use of a single reinforcing bar and steel casing is most commonly used. The steel casing is sometimes referred to as a pipe or hollow structural section (HSS). A micropile utilizing partial length permanent casing and reinforcement is called a composite micropile. A typical composite micropile cross section used for structural foundation support is shown on Figure 1 below.

Micropiles are usually designed in small clusters or groups with each pile typically carrying an equal amount of load. They can be designed to resist a combination of compression, tension, and lateral forces.

Figure 1: Details of a Composite Reinforced Micropile (from FHWA NHI-05-039)



Caltrans typically requires that a composite micropile must be used for structure foundation support. The composite micropiles must consist of an inner steel reinforcing element and outer steel casing. Structure Designer (SD) is responsible for specifying the length of the steel casing. The steel casing is typically extended to the lateral tip elevation. Because of their high slenderness ratio (length/diameter), micropiles must not be used in soils susceptible to liquefaction, lateral spreading, or scour. For new bridges, use of micropiles must be limited to Class S1 Soil as defined by Seismic Design Criteria v2.0, Section 6.1.2. Micropiles may be used in Class S2 Soil if the micropiles are not the primary supporting elements. An example of micropiles that are not primary supporting elements may be in seismic retrofit application where the existing piles are the primary supporting elements. Due to their unique design, the use of micropiles must require approval at the type selection meeting.

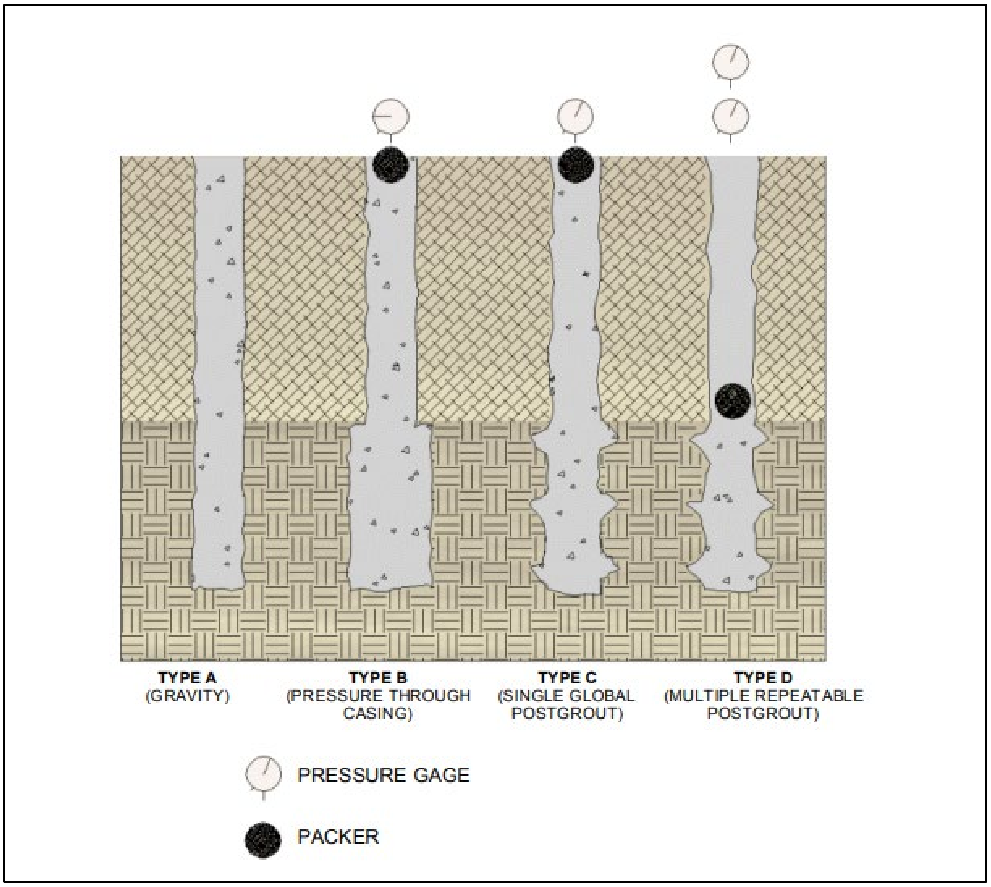
Micropile Classifications

The method of grouting is typically the most important construction process influencing grout/ground bond capacity. AASHTO LRFD BDS classifies micropiles based on the methods of installation/grouting, as follows:

- **Type A:** Micropiles are constructed by placing a sand-cement mortar or neat cement grout in the pile under a gravity head only. Type A grouting is generally used for micropile in rock.
- **Type B:** Micropiles are constructed by injecting a neat cement grout under pressure (typically 6–21 ksf) into the drilled hole while the temporary drill casing or auger is withdrawn.
- **Type C:** Micropiles are grouted as for Type A, followed 15–25 minutes after primary grouting by injection of additional grout under pressure (typically greater than 21 ksf) via a preplaced sleeved grout pipe.
- **Type D:** Micropiles are grouted similar to Type C, but the primary grout is allowed to harden before injecting the secondary grout under pressure (typically 42–170 ksf) with a packer to achieve treatment of specific pile intervals or material horizons.
- **Type E:** Micropiles are constructed by drilling with grout injection through a continuous-thread, hollow-core steel bar. The grout injection serves to flush cuttings, achieve grout penetration into the ground, and stabilize the drill hole. Often the initial grout has a high water to cement ratio and is then replaced with a thicker structural grout near the completion of drilling.

The classification is shown schematically for the various Types in Figure 2 below.

Figure 2: Micropile Types (from FHWA NHI-05-039)



Caltrans divides the design of an individual micropile or a group of micropiles into the following categories:

- **Category A:** Micropiles experiencing primarily axial forces due to axial loading at the top of micropile. This would typically include bridge foundations and may occasionally include walls. For Category A, the contractor determines the length, load testing is performed, and pressure grouting is used. Category A micropiles are sometimes referred to as Case 1 micropiles in the industry.
- **Category L:** Micropiles experiencing primarily shear and bending forces along their length due to lateral loading. This would typically include earth stabilization structures and most walls. For Category L, SD and Geoprofessional (GP) will determine the micropile length, load testing is not performed, and gravity grouting is used. Category L micropiles are sometimes referred to as Case 2 micropiles in the industry.

Design Methods and Requirements

When considering the use of micropiles in foundation design, refer to the following references:

- Caltrans Geotechnical Manual
- Section 10.9 of the AASHTO LRFD BDS with California Amendments (AASHTO LRFD BDS)
- Section 49-5 of the Standard Special Provisions (SSP)
- *Micropile Design and Construction Reference Manual* (FHWA NHI-05-039)

Roles and Responsibilities

The typical responsibilities of the SD and GP for Category A micropile design are listed in Table 1 below.

Table 1: Responsibilities for **Category A** Micropile Design

<table>
<tr><th>Structure Designer (SD)</th><th>Geoprofessional (GP)</th></tr>
<tr><td>• Determine micropile layout and spacing.
• Design of steel reinforcement.
• Shown on plans type and length of permanent steel casing/pipe/HSS.
• Shown on plans grout compressive strength.
• Provide general foundation design information and foundation factored design loads (MTD 3-1, Attachment 1 Tables 3-4 and 3-5).
• Determine the elastic deformation based on estimated micropile bonded length.
• Show on plans the verification load test locations.</td><td>• Provide subsurface information and laboratory testing results.
• Specify verification test locations and the control zones.
• Specify the number of proof load tests required per footing.
• Provide corrosion test results.
• Request creep testing, if needed.
• Provide estimated micropile bonded length* (only to be used for estimating elastic deformation).
• Specify the design tip elevation for tolerable settlement, when applicable.
• Provide soil modulus parameters for p-y curve development.

(All above information must be included in the Foundation Report)</td></tr>
<tr><td colspan="2">• SD and GP together will determine the axial Service Load and Factored Test Load to be used in the load testing and they should be shown on the plans.
• SD and GP together will determine the allowable total top of pile movement at 1.00SL for load testing.</td></tr>
</table>

Note: **Contractor** will determine the micropile bonded length and installation methods to meet the axial load test requirements.
* Refer to Appendix A for estimation of bonded length.

Investigations

For the design of micropiles, the subsurface investigation, laboratory testing, and evaluation of geotechnical design parameters is similar to that for either driven piles or CIDH piles (FHWA NHI-05-039). The geotechnical investigation should adequately define the subsurface conditions for design purposes and be consistent with the standards of practice identified in the Caltrans Geotechnical Manual. The extent of the exploration, field testing, and laboratory testing must give a reasonable degree of confidence in the property measured. The *Micropile Design and Construction Reference Manual* (FHWA NHI-05-039) provides minimum guidelines for boring spacing and depth, as shown in Table 2 below.

Table 2: Guidelines for Minimum Number of Investigation Points and Depth of Investigation
(from FHWA NHI-05-039)

Application	Minimum Number of Investigation Points and Location of Investigation Points	Minimum Depth of Investigation
Deep Foundations (Micropiles for Structural Support)	For substructure (e.g., bridge piers or abutments) widths less than or equal to 30 m (100 ft), a minimum of one investigation point per substructure. For substructure widths greater than 30 m (100 ft), a minimum of two investigation points per substructure. Additional investigation points should be provided if erratic subsurface conditions are encountered.	In soil, depth of investigation should extend below the anticipated micropile tip elevation a minimum of 6 m (20 ft), or a minimum of two times the maximum micropile group dimension, whichever is deeper. All borings should extend through unsuitable strata such as unconsolidated fill, peat, highly organic materials, soft fine-grained soils, and loose coarse-grained soils to reach hard or dense materials. For micropiles bearing on rock, a minimum of 3 m (10 ft) of rock core must be obtained at each investigation point location to verify that the boring has not terminated on a boulder. For micropiles supported on or extending into rock, a minimum of 3 m (10 ft) of rock core, or a length of rock core equal to at least three times the micropile diameter for isolated micropiles or two times the maximum micropile group dimension, whichever is greater, must be extended below the anticipated micropile tip elevation to determine the physical characteristics of rock within the zone of foundation influence.

Corrosion Testing Evaluation

Soil and/or water samples should be collected during the subsurface investigation to determine the corrosion potential at the project site. The corrosion evaluation will be based on Caltrans Corrosion Guidelines. Micropiles are not recommended for use in a corrosive environment. If it is decided to use micropiles in a corrosive environment, the Corrosion Branch must be consulted for mitigation measures.

Micropile Design

Group Capacity

At small micropile spacings, a block type failure mechanism may occur, whereas at larger pile spacings the individual pile failure may occur. It is necessary to check for both failure mechanisms and design for the case that yields the minimum capacity. For determining the reduction in resistance from group effects in compression and tension (uplift), refer to Section 10.9.3.6 and 10.9.3.8 of the AASHTO LRFD BDS, respectively. If the group efficiency factor (η) is less than 1.0, the nominal resistance must be determined as:

$$R_N = \frac{FDL}{\varphi\eta}$$

Where,

R_N = nominal resistance (k)

FDL = factored design load (k)

Φ = resistance factor, 0.7

η = micropile group efficiency factor

Group Settlement

Micropiles in a group can undergo vertical displacement as a result of underlying soft soil layers. The equivalent footing concept, as used for driven pile groups, is used for estimating settlements of micropile groups. The GP should estimate the micropile group displacement when the underlying soil is cohesive in nature and subject to consolidation. Refer to Section 5.10 of the *Micropile Design and Construction Reference Manual* (FHWA NHI-05-039) for step by step procedure for calculating micropile settlement. When a minimum pile penetration is necessary to satisfy the settlement requirement, the GP will specify the design tip elevation for settlement. The settlement design tip will be shown in the Foundation Design Recommendations Table and Pile Data Table in the Foundation Report. However, the contractor will determine the micropile length and installation methods needed to meet the axial load test requirements.

Micropile Load Testing

Micropiles must be load tested in the field to verify the required design loads can be achieved without excessive settlement. There are two types of micropile load testing: verification testing and proof testing.

Verification Testing

The verification testing is performed on sacrificial micropiles prior to construction of production micropiles. The verification test is to verify the design and adequacy of the contractor's drilling, installation, and grouting operations. Each verification micropile must have the identical materials, dimensions, tip elevations, and installation methods as the production micropiles it represents. A sufficient number of verification test micropiles must be provided to represent all the production micropiles. The GP must provide verification micropile locations based on representative subsurface conditions. Since the length of the verification and production micropiles must match, SD and GP should consider performing additional verification tests to allow for optimization of micropile length when there is a wide range in required nominal resistance.

Proof Testing

Proof testing is performed on production micropiles to provide quality assurance. During installation of production micropiles, proof testing is conducted on a specified number of the total production micropiles. The frequency of proof testing must be at least 10%, but not less than 2, of the total micropiles per bridge footing. The proof load test locations will be selected by Caltrans field engineer.

Service Load and Factored Test Load

The load test schedule is based on Service Load (SL) and Factored Test Load (FTL). SL is the maximum axial load for Service Load combination. FTL is typically the highest required nominal resistance of the micropiles. The maximum test load for verification is 1.00 FTL and for proof testing is 0.80FTL. SD and GP together will determine the values of SL and FTL to be used in the load testing. It is recommended that verification and proof testing be performed in tension only, with the FTL equal to the greater of the tension or the compression nominal resistance. Tension load testing is less expensive and allows the ground and/or production piles to be used for reaction to the test load.

Creep Testing

Creep is a primary concern in organic soils, and in cohesive soils with a liquid limit greater than 50 and plasticity index greater than 20 (FHWA NHI-05-039). The creep test consists of measuring the movement of the micropile at a constant load over a specified period of time. If recommended by the GP, creep tests are performed as part of verification and proof tests.

Load Testing Acceptance Criteria

For verification load testing acceptance, the slope of the graph of the applied test load versus the top of micropile movement must not exceed 0.025 in/kip at the maximum test load of 1.00FTL (Caltrans SSP Section 49-5).

For verification and proof load testing, a maximum top of micropile movement at 1.00SL is recommended based on the considerations of the movements of the structure being supported by the micropile foundation. The top of micropile movement is a function of the pile stiffness (elastic deformation) and the grout-to-ground bond movement. GP will estimate the micropile bonded length. The bonded length is assumed to start from the tip of micropile casing/pipe/HSS (assume the casing/pipe/HSS has no geotechnical capacity). Refer to Appendix A for estimation of the micropile bonded length. Once determined, the estimated micropile bonded length is then provided to SD. The estimated bonded length is only to be used for estimating the elastic deformation by SD, and it is **not** to be shown in the Foundation Design Recommendations Table or Pile Data Table. SD and GP together will determine the allowable total top of pile movement at 1.00SL.

Load Test Schedules

The verification and proof load test schedules are listed in the project's Special Provisions. Examples of the load test schedules are shown in Appendix B

Reporting

Foundation Reports for micropiles must comply with the Foundation Reports for Bridges module. Micropile Design tip elevations for compression and tension <u>must not</u> be included in the tables. The GP will specify the micropile design tip elevation for settlement <u>only</u> if a minimum pile penetration is necessary. See Tables 3 and 4 below (micropile design at Abutments 1 and 3 locations).

Table 3: Foundation Design Recommendations Table

Support Location	Pile Type	Pile Cut-off Elev. (feet)	Service-I Limit State Load Per Support (kips)		Total Permissible Support Settlement (in)	Nominal Resistance[1] (kips)				Design Tip Elev. (feet)	Specified Tip Elev.[2] (feet)	Casing Tip Elev.[3] (feet)
						Strength/ Construction		Extreme Event				
			Total	Permanent		Comp. $\varphi = 0.7$	Tension $\varphi = 0.7$	Comp $\varphi = 1.0$	Tension $\varphi = 1.0$			
Abut 1	10-inch Micropile with Casing	___	___	___	___	___	___	N/A	N/A	___	___	___
Abut 3	10-inch Micropile with Casing	___	___	___	___	___	___	N/A	N/A	___ (c)	___	___

Note: Design tip elevations are controlled by (a-I) Compression (Strength Limit), (a-II) Compression (Extreme Event), (c) Settlement

1) Column heading modified from *Required Factored Nominal Resistance* to *Nominal Resistance*.
2) Micropile lengths will be determined by contractor. Micropile settlement design tip indicates the minimum pile length.
3) Casing tip elevations are provided by the structure designer.
4) For CIDH piles, the required nominal tip resistance is shown in parenthesis.

Table 4: Pile Data Table

Support Location	Pile Type	Nominal Resistance (kips)		Design Tip Elev. (feet)	Specified Elev. [1] (feet)	Casing Tip Elev.[2] (feet)
		Compression	Tension			
Abut 1	10-inch Micropile with Casing	___	___	___	___	___
Abut 3	10-inch Micropile with Casing	___	___	___(c)	___	___

Note: Design tip elevations are controlled by (a) Compression (c) Settlement

1) Micropile lengths will be determined by contractor. Micropile settlement design tip indicates the minimum pile length.
2) Casing tip elevations are provided by the structure designer.

Appendix A: Micropile Bond Length

The nominal grout-to-ground bond resistance over the bonded length of a micropile must be taken as:

$$R_s = \pi d_b \alpha_b L_b$$

Where,

R_s = nominal bond resistance (k)

d_b = diameter of micropile drilled hole through bonded length (feet)

α_b = nominal micropile grout-to-ground bond strength (ksf)

L_b = micropile bonded length (feet)

The maximum test load for load testing is 1.00 FTL (factored test load), therefore, the equation above can be rewritten and rearranged as:

$$L_b = \frac{FTL}{\pi d_b \alpha_b}$$

As a guide, Table A-1 below, can be used to estimate the grout-to-ground bond strength. Refer to Micropile Classifications section of this module for micropile types.

Table A1: Summary of Typical Grout-to-Ground Bond Strength (α_b)
(from Table C10.9.3.5.2-1 of AASHTO LRFD BDS)

Soil/Rock Description	Typical Range of Grout-to-Ground Bond Nominal Resistance for Micropile Types (ksf)				
	Type A	Type B	Type C	Type D	Type E
Silt & Clay (some sand) (soft medium plastic)	0.7–1.4	0.7–2.0	0.7–2.5	0.7–3.0	0.7–2.0
Silt & Clay (some sand) (stiff, dense to very dense)	0.7–2.5	1.4–4.0	2.0–4.0	2.0–4.0	1.4–4.0
Sand (some silt) (fine, loose-medium dense)	1.4–3.0	1.4–4.0	2.0–4.0	2.0–5.0	1.4–5.0
Sand (some silt, gravel) (fine-coarse, medium-very dense)	2.0–4.5	2.5–7.5	3.0–7.5	3.0–8.0	2.5–7.5
Gravel (some sand) (medium-very dense)	2.0–5.5	2.5–7.5	3.0–7.5	3.0–8.0	2.5–7.5
Glacial Till (silt, sand, gravel) (medium-very dense, cemented)	2.0–4.0	2.0–6.5	2.5–6.5	2.5–7.0	2.0–6.5
Soft Shales (fresh-moderate fracturing, little to no weathering)	4.3–11.5	N/A	N/A	N/A	N/A
Slates and Hard Shales (fresh-moderate fracturing, little to no weathering)	10.8–28.8	N/A	N/A	N/A	N/A
Limestone (fresh-moderate fracturing, little to no weathering)	21.6–43.2	N/A	N/A	N/A	N/A
Sandstone (fresh-moderate fracturing, little to no weathering)	10.8–36.0	N/A	N/A	N/A	N/A
Granite and Basalt (fresh-moderate fracturing, little to no weathering)	28.8–87.7	N/A	N/A	N/A	N/A

Appendix B: Testing Schedules

Table B1: Verification Load Test Schedule (from 2018 SSP)

Load Increment	Hold Time (minutes)
AL	Until stable
0.25SL	1-2
AL	Until stable
0.25SL	1-2
0.50SL	1-2
AL	Until stable
0.25SL	1-2
0.50SL	1-2
0.75SL	1-2
AL	Until stable
0.25SL	1-2
0.50SL	1-2
0.75SL	1-2
1.00SL	5*
AL	Until stable
0.25SL	1-2
0.50SL	1-2
0.75SL	1-2
1.00SL	1-2
0.80SL + 0.20FTL	1-2
0.60SL + 0.40FTL	1-2
0.40SL + 0.60FTL	1-2
0.20SL + 0.80FTL	1-2
1.00FTL**	5
0.75FTL	1-2
0.50FTL	1-2
0.25FTL	1-2
AL	Until stable

AL=alignment load, 0.10SL
SL=service load
FTL=factored test load
*Hold time up to 60 minutes if creep test is recommended, refer to Section 49-5 the Standard Special Provisions for details.
**Maximum test load

Table B2: Proof Load Test Schedule (from 2018 SSP)

Load Increment	Hold Time (minutes)
AL	Until stable
0.25SL	1-2
0.50SL	1-2
0.75SL	1-2
1.00SL	5*
0.80SL + 0.20(0.80FTL)	1-2
0.60SL + 0.40(0.80FTL)	1-2
0.40SL + 0.60(0.80FTL)	1-2
0.20SL + 0.80(0.80FTL)	1-2
0.80FTL**	5
AL	Until stable

AL=alignment load, 0.10SL
SL=service load
FTL=factored test load
* Hold time up to 60 minutes if creep test is recommended, refer to Section 49-5 the Standard Special Provisions for details
**Maximum test load