10.7 PILES AND SHAFTS

This BDM provides general information for the design of driven piles and drilled shafts used as deep foundation systems. Micropiles and vertical ground anchors (tie-downs), as well as alternative deep foundation systems, are discussed elsewhere. Refer to the Bridge Design Processes and Procedures Manual (BDPPM) or the OSFP Information and Procedures Guide (I&PG) for information related to design procedures and technical communications between the structural designer (SD) and geoprofessional required during the design process.

10.7.1 DEFINITION

Deep foundations are structural components that, in comparison to shallow foundations, transfer loads into deeper layers of earth materials. Considering the method of construction, deep foundations (generically referred to herein as piles) can be classified as driven piles and drilled shafts, also known as cast-in-drilled-hole (CIDH) concrete piles. Piles can be used in a group with a pile cap, as a single pile/shaft supporting a column, or as a pile extension supporting slab bridges and connected to the superstructure.

10.7.2 CLASSIFICATION OF PILES AND SHAFTS

To simplify the design process, structural details and structural resistances have been provided for smaller piles referred to as Standard Plan (Class) Piles. The Standard Plans, Sheets B2-3 (*16" AND 24" CAST-IN-DRILLED-HOLE CONCRETE PILE*), B2-5 (*PILE DETAILS CLASS 90 AND CLASS 140*), and B2-8 (*PILE DETAILS CLASS 200*) provide structural details and nominal axial structural resistances in tension and compression. The connection of Standard Plan piles to the cap is assumed to be pinned without transferring any appreciable moment to the pile cap.

Considering the type of materials used for construction, the method of construction, and structural or geotechnical performance, driven piles and drilled shafts can be further classified as follows.

10.7.2.1 Driven Piles

Driven piles may be precast prestressed concrete, cast-in-steel-shell (CISS), rolled HP sections, steel pipe, or timber. Driven piles are to be installed with an impact hammer, and resistance shall be verified in the field.

Piles with a solid cross section, closed-end tip, or with lugs installed near the tip of the pile that displace the soil around the pile during driving are classified as displacement piles. Open cross sections, such as steel H piles and open-ended pipe piles, will either displace the soil or cut through the soil (non-displacement) depending on the diameter of the pile (for pipe piles), properties of the soil, and depth of pile penetration. Typically, steel

H piles and open-ended pipe piles 24 inches and greater in diameter are non-displacement piles. Non-displacement piles are useful for deeper penetrations or where hard driving conditions are expected.

Site-specific issues, including noise, vibration, ground heave, settlement, limited headroom, constructability, and drivability, should be considered when selecting driven piles. Liquefaction, scour, or other conditions may govern the calculated specified tip elevation, and therefore, the nominal driving resistance may exceed the controlling nominal resistance. When hard driving is expected, Geotechnical Services (GS) may perform a drivability analysis to verify that the piles can be driven to the specified tip elevation with acceptable driving stresses and blow counts.

Except for the CISS, driven piles may be battered to reduce the resultant shear force acting on the foundation system. However, battered piles are not recommended when the foundation system is subject to downdrag. Battered piles are not used to support foundations of bents and piers in Class S2 soil as specified in Article 10.7.1.4 of AASHTO LRFD Bridge Design Specifications and California Amendments (AASHTO-CA BDS).

10.7.2.1.1 Steel H Piles

Steel H Pile (HP) sections are usually specified where displacement piles cannot penetrate foundation materials such as rock, cobbles, gravel, and dense sand. Steel HP sections are also preferable for longer piles because they can be spliced more easily than precast prestressed concrete piles. Steel H piles may not be economical where highly corrosive soil and/or water is encountered.

If steel H piles are allowed as an alternative to a Standard Plan Class pile, the SD should provide allowable HP sizes to the Specification Engineer. The HP 14x89 steel pile is usually specified for nominal axial structural resistance (in compression) of 400 kips, HP 10x57 for 280 kips, and HP 10x42 for 180 kips. The SD should note in the Structure P&Q Submittal Checklist when other steel sections are acceptable for substitution and verify with the Cost Estimating Branch that a recommended non-standard HP section is available. Larger pile sections, such as HP14x117 or HP16x88, may be required if increased lateral load resistance is needed or hard driving is anticipated. Pile anchors are designed for the applied loads, and the details are shown on the plans.

10.7.2.1.2 Cast-in-Steel-Shell (CISS) Concrete Piles and Steel Pipe Piles

CISS concrete piles are driven steel shells filled with cast-in-place reinforced concrete no deeper than the shell tip elevation. CISS concrete piles provide excellent structural resistance against horizontal loads and are a good alternative under the following conditions:

1) where poor soil conditions exist, such as soft bay mud deposits or loose sands.
2) if liquefaction and/or scour potential exist, that will cause long unsupported pile lengths.
3) if large lateral soil movements are anticipated (such as lateral spreading).

During pile driving, CISS concrete piles may develop a soil plug at the bottom. Generally, open-ended pipe piles up to 16 inches in diameter tend to plug during driving, while diameters 24 inches and greater tend not to plug. The soil plug is left intact at the bottom of the pile to prevent the pile from being undermined during the cleaning process. The soil plug may also be utilized to counteract the hydrostatic forces of groundwater when the pile is to be internally cleaned out. The use of a seal course may be required for high hydraulic head and permeable soils, as discussed in BDM 10.3. The Foundation Report specifies the top of soil plug elevation or soil plug length and the seal course thickness, if applicable, for open-ended steel shells. Considerations for driving stresses are the same for CISS and steel pipe piles.

Shear rings are used in CISS concrete piles and CIDH concrete piles with permanent steel casing when composite action for axial and flexural capacity is required. BDM 10.5 provides the necessary information for the design of the shear rings.

10.7.2.1.3 Precast-Prestressed Concrete Piles

Precast-prestressed (PC-PS) concrete piles are usually cheaper than other alternatives; however, challenges in cutting or splicing PC-PS concrete piles have limited their application. Furthermore, PC-PS concrete piles are more prone to damage during pile driving that may require further evaluation.

According to STP 10.7, precast-prestressed concrete piles shown in Standard Plans B2-5 and B2-8 shall not be used as pile extensions to support slab bridges. Refer to Appendix B of the MTD 20-7 for structural details of PC-PS pile extensions.

10.7.2.1.4 Timber Piles

The use of timber piles is mostly limited to temporary structures. For timber piles to be used in permanent structures, the pile cut-off should be below the lowest possible groundwater level and with no exposure to marine borers. Because of their flexibility, low ductility, and difficult cap connections, timber piles are not permitted to be used as seismic critical members.

The nominal resistance for timber piles in compression should be limited to 180 kips. Pile information for timber piles should be detailed on the contract plans, similar to other types of driven piles.

10.7.2.2 Drilled Shafts (CIDH Concrete Piles)

CIDH concrete piles are a possible solution when pile driving is restricted. A CIDH concrete pile is more advantageous than a driven pile when installation noise and/or vibration are concerns; however, disposal of hazardous drill spoils may be costly. CIDH concrete piles cannot be battered because of the increased risk of caving and the difficulty of placing concrete and reinforcement in a sloping hole.

When groundwater is anticipated, CIDH concrete piles are designed to accommodate construction techniques associated with drilled shafts constructed in wet holes.

Considering seasonal fluctuations of groundwater elevation and the possibility of the presence of perched groundwater, STP 10.7 requires showing Polyvinyle Chloride (PVC) inspection pipes on the plans. Furthermore, the contractor may select to use the wet construction method to control caving in dry conditions. PVC inspection pipes are installed to permit Gamma-Gamma Logging (GGL) and Cross-hole Sonic Logging (CSL) tests of the CIDH concrete piles. Refer to AASHTO-CA BDS (Article 10.8.1.3) for reinforcing steel clearance requirements in conjunction with inspection pipes. Attachment 10.7.A1 shows the information needed to develop the layout of inspection pipes in CIDH concrete piles.

Conventional standard sizes for CIDH augers and steel pipes (shells/casings) are shown in Attachment 10.7.A2. These sizes are preferred for CISS concrete piles and CIDH concrete piles with or without a permanent steel casing.

Casings can be left in place permanently or removed during concrete placement. The permanent steel casing is smooth-walled and contributes to the structural resistance of the pile, as discussed in BDM 10.5. A permanent steel casing is different from a "driven steel shell", as the shell provides extra geotechnical axial resistance to the pile. A permanent steel casing may be driven, drilled, vibrated, or oscillated into place, whereas a shell is driven to the specified tip elevation and a required nominal geotechnical resistance.

When caving conditions exist, the geoprofessional may recommend the use of a permanent steel casing. A permanent steel casing might also be required for CIDH concrete piles very near utilities, railroads, or traffic (especially in medians) where caving would threaten existing facilities. If the contractor proposes to eliminate the casing during construction of CIDH piles (with permanent steel casing) and the casing is not needed for structural reasons, the structure designer needs to acquire concurrence from the geoprofessional before approval of the contractor's proposal.

For type-II shafts (refer to Caltrans' SDC for definition of type-II shafts) 5-foot in diameter and larger, a construction joint is required below the embedded column rebar cage. The construction joint will allow the contractor to place the CIDH concrete without supporting the column rebar and to cast concrete for the rest of the shaft and column in a dry condition. Permanent Corrugated Metal Pipe (CMP) casing is mostly used to construct type-II shafts with a construction joint and does not contribute to the geotechnical or structural resistances of the shaft. The thickness of the permanent CMP casing is decided by the contractor; however, the inside diameter and the tip elevation (or length) are shown on the plans. The inside diameter of the permanent CMP casing should not be more than 2 feet larger than the diameter of the CIDH concrete pile. The cut-off elevation of the permanent CMP casing should not extend above the top of the drilled hole or the final grade, whichever is lower. The geoprofessional provides the tip elevation of the permanent CMP casing in the foundation report based on subsurface conditions and in coordination with the SD to ensure adequate embedment below the construction joint and verifies that it does not affect the zone of geotechnical resistance.

When considering CIDH concrete piles in wet conditions, caution should be exercised in the following cases:

1) lack of redundancy in single column bents;

2) soft cohesive soils, loose sands, or boulders at the support location (constructability); and
3) the presence of high groundwater pressure that will make it difficult to establish a required differential drilling slurry head for construction.

Driven piles should be considered for the above situations. If driven piles cannot be used, the designer should consider the risk of possibility of anomalies in the shaft.

Both tip and side resistances of CIDH concrete piles are developed in response to pile vertical displacement. The maximum or peak resistance values are seldom cumulative because they are not likely to occur at the same displacement. Since side resistance is usually mobilized at a small displacement, CIDH concrete piles rely on side resistance for most of their capacity, particularly under Service Limit State loads. The mobilization of tip resistance for CIDH concrete piles is uncertain. The situation is worse in wet construction conditions, where soft, compressible drill spoils and questionable concrete quality are both possible at the pile tip. Displacement compatibility is considered when adding tip resistance and side resistance. If the geoprofessional relies on large movements to mobilize tip resistance, superstructure tolerance to such movements (settlement) shall be checked.

To ensure constructability and quality, STP 10.7 requires the length of CIDH concrete piles to be limited to 30 times the smallest diameter of the pile measured from the cut-off point of the shaft. Tip elevation revision is generally not allowed for drilled shafts. An engineered length for skin friction resistance primarily controls the specified CIDH concrete pile depth. When the specified tip elevation is controlled by lateral loads, constructing to the specified tip elevation is particularly important for single column bents, where a change in the pile's lateral stiffness could affect the dynamic response of the entire structure.

When smaller CISS or CIDH concrete piles need to be fixed to the cap or abutment stem, the use of hooks at the cut-off point of the piles may be challenging. The designer should examine the layout of the hooks to make sure that enough space is provided for the passage of the tremie tube as well as the slurry exit tubes. As the contractor may need to use temporary casing, the bars should not be bent outwards. In such cases, the depth of the cap or the stem may need to be increased to develop the bars without using hooks.

Column shafts with a pin connection between the column and the shaft may be advantageous for multi-column piers with short columns. A high strength pipe or a small diameter cage may be used as the pin reinforcement. The proposed pin connection details should be discussed at the bridge type selection meeting. The pin connection reduces overstrength moment and shear at the base of the column, therefore reducing shear and moment demands in the shaft when designed for seismic loads. The use of a pin connection also reduces the depth of the construction joint (when required) in the shaft and eliminates any overlap between column and shaft reinforcement. The shaft enlargement is not required when connecting the column and the shaft with a pin; however, the diameter of the shaft should be at least equal to the maximum size of the column. The shaft is designed with the same concept as type-II shafts, considering the very limited plastic moment of the pin connection. When a small diameter cage is used for the pin connection, the connection is designed to provide adequate shear friction capacity, and the longitudinal reinforcement of the pin is developed in both the column and the shaft in accordance with the AASHTO-CA BDS requirements. Stainless steel bar reinforcement shall be used for the pin connection between the column and the shaft. The stainless steel bar reinforcement should comply with the requirements of Non-Standard Special Provision (NSSP) 52-8 (Stainless Steel Bar Reinforcement).

10.7.2.2.1 Rock Sockets

Rock sockets are drilled shafts that require drilling and excavation into underlying rock layers. Rock sockets are generally utilized to transfer structural loads into rock overlain by soil and/or overburden materials. Advances in drilling technologies and equipment have allowed contractors to use methods of drilling holes through rock without the need for blasting and mining methods used in the construction of mined shafts. In cases where hard rock drilling is anticipated, and conventional drilling tools (e.g., soil augers) may not be effective in advancing the hole, the rock socket zone shall be identified, and the pay limits of the rock socket shall be shown on the plans (refer to the *CIDH Pile Foundation* module of the *Caltrans' Geotechnical Manual* for more details). Additionally, pile cut-off and tip elevations need to be shown in the Pile Data Table. Rock sockets can develop large geotechnical axial resistances in relatively short socket lengths; therefore, a review of the pile placement plans and field inspection during construction by the geoprofessional may be necessary to verify that the construction method, desired length, and rock conditions are as anticipated. For end bearing piles, the construction specifications should accommodate inspection of the bottom of the shaft utilizing the Shaft Inspection Device (SID) or similar devices.

10.7.2.3 Mined Shafts

Mined shafts are used when site conditions indicate that excavation by hand, blasting, and mechanical/chemical splitting of the rock is needed. Mined shaft excavation in rock is usually more expensive than methods using drilling equipment, and the pay limits need to be clearly defined. Projects that utilize this pay item include difficult access locations where vertical or inclined shafts in rock are required. The mined shaft cut-off elevation and tip elevation (upper and lower limits of the hard material) should be shown in the Pile Data Table. The pay limits for Structure Excavation (mined shaft) and Structure Concrete (mined shaft) are shown on the plans.

10.7.2.4 Pile Extensions

When pile extensions are selected, the pile (below the finished grade) and the extension (above the finished grade) shall be designed as seismic critical members following SDC requirements. Upon request, the geoprofessional will provide soil profile data for the designer's analysis of the lateral response of the pile extension. The contract plans should give the option to furnish and drive full-length precast prestressed piles or steel pipe piles. Driven pile extensions should be avoided where subsurface conditions include very hard driving conditions, where the pile could be damaged while driving, or hard cobbles and boulders may cause the pile to deflect from the vertical condition. An extended pipe pile shall be filled with reinforced concrete from at least one foot below the finished grade up to the bent cap. Special seismic detailing may be required to control plastic hinge locations in pipe pile extensions. When precast-prestressed concrete pile extensions are used, attention should be given to the possibility of requiring pile splices in the field when the geotechnical axial resistance of the pile may not be accurately estimated during design.

10.7.3 DESIGN CONSIDERATIONS

According to AASHTO-CA BDS, deep foundations shall meet requirements for Service, Strength, Extreme Event, and Construction (only for abutments) limit states as summarized here.

10.7.3.1 Settlement

In general, the total permissible settlement under the Service-I Limit State should be limited to the values specified in Article 3.4.1 of AASHTO-CA BDS. The SD will provide both total and permanent Service-I Limit State support loads to the geoprofessional. When evaluating settlement, the geoprofessional should consider group effects.

10.7.3.2 Permissible Horizontal Load

The permissible horizontal load for deep foundations at abutments, which is used for the Service-I Limit State load combination check, is the horizontal load that results in the permissible horizontal displacement. According to AASHTO-CA BDS (Article 10.5.2.2), the permissible horizontal displacement is 0.25 inch calculated at the top or cut-off elevation of the pile. However, the limit may be increased to 0.5 inch provided that the pile's factored nominal resistance and stresses meet the requirements for all applicable limit states load combinations. In the case of the use of battered piles at abutments, the horizontal component of a battered pile's axial load may be subtracted from the total lateral load to determine the applied horizontal or lateral force acting on pile foundations.

10.7.3.3 Nominal Resistance in Uplift (Tension)

The Standard Plans, Sheets B2-3, B2-5, and B2-8, show structural details for the 16″ and 24″ CIDH, Class 90, Class 140, and Class 200 Standard Plan piles, as well as nominal axial structural resistance for both tension and compression. The demand for uplift resistance at any pile is limited to the structural resistance of the pile in tension and the pile's connection to the footing.

The SD and the geoprofessional shall verify that the required nominal axial resistance in tension can be obtained geotechnically. Short piles with large end bearing contributions may have limited tensile capacity. When liquefaction or scour is anticipated, the side resistance of the susceptible soil layers varies depending on the load combination considered in the design.

Group effects are considered by the geoprofessional when evaluating nominal resistance in tension. The factored design load for Strength or Extreme Event Limit States shall not exceed the factored nominal resistance in tension for the respective limit state. The resistance factors for tension under Strength and Extreme Event Limit States are provided in the AASHTO-CA BDS.

10.7.3.4 Horizontal Resistance

A soil-structure interaction analysis, such as using p-y (Load-Deflection) curves, is required to determine the horizontal resistance of the piles. Group effects should be considered when evaluating the horizontal resistance of pile groups. P-multipliers used to incorporate group effects in the p-y method of analysis are provided in Section 10.7.2.4 of the AASHTO-CA BDS. The passive resistance provided by the embedded pile cap backfill is ignored for the Service and Strength Limit State evaluation of pile groups. However, the contribution of passive soil pressure and side friction to the lateral resistance of the cap is considered in the seismic design of pile groups, as discussed in SDC 6.2.3.

In general, the SD will perform the lateral load analysis. The SD will determine when such analysis is necessary and will request the geoprofessional to provide an input soil profile and spring data. In some cases, the SD may request that the geoprofessional perform lateral load analysis.

To increase horizontal capacity, driven piles may be battered at abutments. The horizontal component of the axial load in the battered piles may be subtracted from the horizontal loads acting on the abutment.

10.7.3.4.1 Pile Length for Horizontal Load

To obtain stability against seismic horizontal loads, the pile length should not be less than the critical length multiplied by an embedment factor specified in SDC Article 6.2.6. A lateral stability analysis, in which the governing design seismic lateral load is applied at the cut-off point of the pile, and the pile length is varied to develop a pile length versus pile top deflection plot, is necessary to determine the critical length. The critical length is the length of the pile for which greater lengths do not significantly reduce the deflection at the pile cut-off point.

Lateral stability analysis is not required for pile groups with five or more piles in Class S1 soil (per SDC soil classification). The foundation recommendations do not typically consider pile penetration depths for lateral loading, as the SD is responsible for lateral tip calculations. However, the SD may request the geoprofessional to perform a stability analysis of the pile. If lateral tip elevation is the lowest design tip elevation, the SD should inform the geoprofessional to verify the pile constructability and update the Foundation Report. The SD shall verify that adequate pile penetration is provided for structural stability against scour, liquefaction, or soil lateral spreading induced by seismic events.

10.7.3.4.2 Nominal Horizontal Resistance (Strength and Extreme Event)

The factored lateral load for Strength/Construction or Extreme Event Limit States is limited to the factored nominal horizontal resistance for the respective limit state. The nominal horizontal resistance under Strength/Construction or Extreme Event Limit States is taken as equal to the applied horizontal load at which the structural capacity of the pile under the combined effects of bending and axial load or under shear (whichever is smaller) is reached.

The Class piles detailed in the Standard Plans are designed to pin at the pile cap without transferring any appreciable moment to the structure. Fixed head piles designed to transfer moment to the pile cap require a case-by-case design that considers the effects of shear, moment, axial load, and stability. The foundation design should take into consideration lateral pile demands, pile stiffness, and soil capacity.

10.7.4 TEST PILES AND FIELD VERIFICATION

Dynamic Monitoring is required for field verification of driven piles with a diameter, or greatest cross-section dimension of 18" and larger, or piles with a Nominal Driving Resistance greater than 600 Kips.

Field verification of nominal geotechnical axial resistance in compression using pile load test is required for driven piles with a diameter or the greatest cross sectional side dimension larger than 36 inches. Furthermore, the geoprofessional may recommend pile load test in other situations.

A five-pile load test pile group is required when both tension and compression tests are required. A three-pile load test pile group is adequate if only a tension test is required. Refer to Standard Plans B2-9, B2-10, and B2-11 for details and pay limits of Caltrans Standard Plan piles when a pile load test is recommended.

The Structure Plans should show pile load test locations, control zones, connection details, and the layout of both anchor and load test piles. If possible, the test piles should be incorporated into the permanent structure.

10.7.5 NON-DESTRUCTIVE TESTING OF WELDS FOR STEEL PILES, SHELLS, AND CASINGS

Steel pipe piles, permanent steel casings, and steel shells can be classified as Redundant (R) or Non-redundant (N). Examples of class N piles are: unfilled pipe piles or CISS concrete piles installed in a pile group of fewer than 5 piles and designed for non-elastic performance, permanent steel casings shown on the plans that are required for strength of type-I shafts, and permanent steel casings used in type-II shafts supporting single column bents. Examples of redundant piles are pile groups with at least 5 piles and steel casings used in type-II shafts in multi-column bents.

For non-redundant piling, the construction specifications should indicate the zone of the pile that will require non-destructive testing (NDT) of welded splices. According to the current std specifications (49-2.02A(4)(b)(iii)(B) and 2.02A(4)(b)(iii)(C)), a minimum of

25% NDT is required on circumferential butt welds (splices) in both field and shop welds, regardless of zone. In addition to visual inspection, additional NDT requirements for all non-redundant piles are provided in the construction specifications. Because the eventual pile tip elevation is uncertain, the specification of "no-splice zones" in steel piles should be avoided. Section 49-2.02 of Standard Specifications provides welding requirements for steel pipe piles.

10.7.6 CORROSION

For structural elements, a site is considered corrosive when one or more of the following conditions exist (AASHTO-CA BDS Article 10.7.5):

- The pH is 5.50 or less.
- The soil contains a chloride concentration of 500 ppm or greater.
- The soil contains a sulfate concentration of 1500 ppm or greater.

A minimum resistivity value for soil and/ or water less than or equal to 1500 ohm-cm indicates the presence of quantities of soluble salts with a higher propensity for corrosion.

For structural elements in soil, the region of greatest concern for corrosion is the portion of the element from the soil surface down to the lowest known groundwater table elevation. This region of the soil typically has a source of oxygen to sustain corrosion.

The Foundation Report will indicate whether the site is corrosive or not. For additional assistance regarding corrosion protection of deep foundations, contact the Corrosion Group of the Field and Forensic Services (FFS) of METS. The SD should consider the effect of corrosion in the design of steel and concrete piles.

10.7.6.1 Steel Piling

Steel piling may be used in corrosive soil and water environments, provided that adequate corrosion mitigation measures are specified. Caltrans typically includes a corrosion allowance (sacrificial metal loss) for steel pile foundations. Other corrosion mitigation measures may include coatings and/or cathodic protection. However, steel coating may be subject to removal during pile driving, exposing the underlying steel to a corrosive environment. The Corrosion Branch of METS should be consulted prior to recommending coatings for steel piles.

Corrosion rates for steel piling exposed to corrosive soil and water are provided in AASHTO-CA BDS, Article 10.7.5. The 14-inch and 16-inch Alternative 'W' class pipe piles shown in Standard Plans B2-5 and B2-8, respectively, have been predesigned for a corrosion rate of 0.001 inch per year. The SD shall evaluate the structural performance of such piles when exposed to higher corrosion rates. If the SD is considering steel piling in a scour zone, this alternative should be discussed with the Corrosion Branch of METS regarding applicable corrosion rates.

The corrosion loss should be doubled for steel H-piling since there are two surfaces on either side of the web and flanges that are exposed to corrosive soil and/or water. For

CIDH casings, CISS concrete piles, and plugged pipe piles, the corrosion allowance is only needed for the exterior surface.

For CISS concrete piles or cased CIDH concrete piles in waterways, considering the fluctuation of the scour zone during the service life of the bridge, the use of coatings for corrosion mitigation is not recommended. The corrosion loss during the service life of the bridge should be considered in design by adding corrosion allowance to the required structural thickness of the casing or shell.

10.7.6.2 Concrete Piling

Reinforced concrete piles shall be designed in accordance with AASHTO-CA BDS Article 5.10.1, "Concrete Cover". This article includes specific information regarding concrete cover, use of supplementary cementitious materials, use of a reduced water-to-cementitious material ratio concrete mix, and epoxy coated reinforcing steel for corrosion mitigation against exposure to corrosive soil and/or water.

Furthermore, to facilitate construction of the drilled shafts, the minimum concrete cover to reinforcement (including locations where epoxy coated rebar is required) will be according to Table 10.8.1.3-1 of AASHTO-CA BDS. For shaft capacity calculations, where the concrete cover is more than 3 inches, only 3 inches of cover is assumed effective and shall be used in structural calculations.

10.7.7 REFERENCES

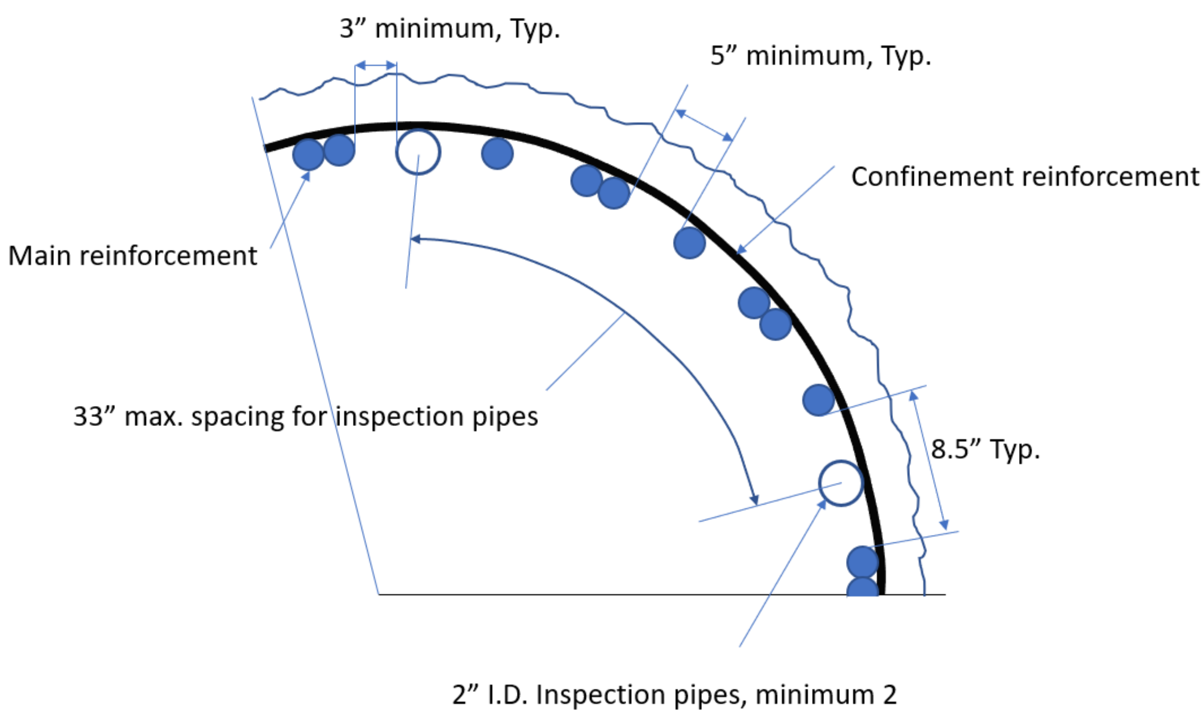
1. AASHTO. (2017). *AASHTO LRFD Bridge Design Specifications*, 8th Edition, American Association of State Highway and Transportation Officials, Washington DC.
2. Caltrans. (2016). Memo to Designers 20-7 *Seismic Design of Slab Bridges*, California Department of Transportation, Sacramento, CA
3. Caltrans. (2019). *California Amendments to AASHTO LRFD Bridge Design Specifications, 8th Edition*, California Department of Transportation, Sacramento, CA.
4. Caltrans. (2022). Bridge Design Memo 10.5 *Composite Cased Piles*, California Department of Transportation, Sacramento, CA.
5. Caltrans. (2024). Bridge Design Memo 10.3 *Foundations with Seal Course*, California Department of Transportation, Sacramento, CA.
6. Caltrans. (2025). *Caltrans' Seismic Design Criteria* (SDC) 2.1, California Department of Transportation, Sacramento, CA.
7. Caltrans. (2025). STP 10.7 *Piles and Shafts*, California Department of Transportation, Sacramento, CA.

ATTACHMENT 10.7.A1: CIDH INSPECTION PIPE LAYOUT

The number of inspection pipes is determined by the SD based on the spacing requirements shown in Figure 10.7.A1-1, with at least two pipes per pile. Inspection pipes shall always be shown on the plans. However, inspection pipes need not be installed if the drilled hole is dry or dewatered, as specified in section 49-3.02 of the Standard Specifications.

Inspection pipes are placed on the interior side of the outermost hoops and in contact with them. If inner hoops are shown, the clearance between the outer and inner hoops should allow for the installation of the PVC inspection pipes. Bar couplers are not shown on the plans; however, they need to be laid out in a staggered pattern.

For type-I shafts, the maximum center-to-center spacing of longitudinal reinforcement shall be 10 inches for shafts 5 ft in diameter and smaller and 12 inches for shaft diameters larger than 5 ft (SDC 8.4.2). This spacing limit may be increased at inspection pipe locations to allow a minimum clear spacing of 3 in.to inspection pipes.



<u>Partial Plan View</u>

Figure 10.7.A1-1: Typical Layout of Inspection Pipes in CIDH Concrete Piles

ATTACHMENT 10.7.A2: CONVENTIONAL STANDARD SIZES

Design engineers should indicate standard US Customary sizes for CIDH concrete piling on the contract plans. Standard metric sizes may not exactly match the standard US customary sizes, and special attention is needed if the contractor will be using metric drilling tools. Available equivalent metric sizes are included in Table 10.7.A2-1. The designer shall verify if the available metric equivalent is acceptable.

Table 10.7.A2-1 Conventional Standard Sizes of CIDH Concrete Piles

Standard US Customary Sizes (in.)	Metric Equivalent (mm)	Standard US Customary Sizes (in.)	Metric Equivalent (mm)
14	-	66	1650
16	-	72	1800
18	-	78	2000
24	600/660	84	2200
30	-	90	-
36	900	96	2500
42	1080	108	2800
48	1200	120	3000
54	-	132	3300
60	1500	144	3800
Cont.	*Cont*.	156	-

Design engineers should indicate the industry's standard US Customary sizes for pipe piles, casings, and shells on the contract plans as listed in Table 10.7.A2-2. The designated sizes specify the outside diameter and thickness of the pipe. Pipe diameters greater than 60 in. are non-standard, and any combination of diameter and thickness can be fabricated.

Table 10.7.A2-2 Standard US Customary Sizes for Pipe Piles, Casings, and Shells

Standard US Customary Size	Equivalent Metric Size
14 x 0.179	PP360 x 4.55
14 x 0.250	PP 360 x 6.35
14 x 0.375	PP 360 x 9.53
14 x 0.438	PP 360 x 11.12
16 x 0.500	PP 406 x 12.70
18 x T"	PP 460 x T
20 x T"	PP 508 x T
22 x T"	PP 559 x T
24 x T"	PP 610 x T
26 x T"	PP 660 x T
28 x T"	PP 711 x T
30 x T"	PP 762 x T
32 x T"	PP 813 x T
34 x T"	PP 864 x T
36 x T"	PP 914 x T
38 x T"	PP 965 x T
40 x T"	PP 1016 x T
42 x T"	PP 1067 x T
44 x T"	PP 1118 x T
48 x T"	PP 1219 x T
60 x T"	PP 1524 x T

In some projects, oscillator/rotator casing may be required due to environmental constraints or poor soil characteristics. The diameter of the oscillator's segmental casings may not exactly match the diameter of the shaft shown on the plans. Table 10.7.A2-3 provides the size of an oscillator's segmental casings and the expected outside diameter of the shaft for different standard sizes of CIDH concrete piles listed in Table 10.7.A2-1. The information in this table has been developed based on providing at least 3 inches of cover; however, the cover may be slightly different than the required cover.

Table 10.7.A2-3 Final (As-built) Diameter of CIDH Concrete Piles when Installed by Oscillation

CIDH Standard Size (in.)	Nominal Size of the Oscillator to be Used (mm)	Expected CIDH Outside Diameter after Construction (in.)
24	600	24.6
30	750	30.6
36	900	36.5
42	1080	43.6
48	1200	48.3
54	1500	60.1
60	1500	60.1
66	1800	71.9
72	1800	71.9
78	2000	79.8
84	2200	87.7
90	2200	87.7
96	2500	99.5
108	2800	111.3
120	3000	119.2
132	3300/3352	130.9/132.9
144	3600	142.7
162	4200	166.5

ATTACHMENT 10.7.A3: EXAMPLES OF DESIGN PROCESS

This attachment presents examples of information exchanged between the SD and the geoprofessional during the design process for different types of deep foundation systems. The tables provide specific information to be exchanged for each type of pile; however, the numbers shown in the tables are explanatory.

At preliminary design, the geoprofessional provides a Preliminary Foundation Report (PFR) as shown in the *Foundation Reports for Bridges* in the *Caltrans Geotechnical Manual*. The Preliminary Foundation Design Recommendations table is provided in the PFR. The SD provides preliminary foundation information to the geoprofessional using the Preliminary Foundation Design Data Sheet, shown in Table 10.7.A3-1 (Table 4a of Bridge Design Form BD-0131), as part of the request for a Preliminary Foundation Report.

Table 10.7.A3-1: Example of Preliminary Foundation Information

Support Location	Foundation Type(s) Considered	Estimate of Maximum Factored Compression Loads (kips)[1,2]	Estimate of Maximum Factored Tension Loads (kips)[1,2]
Abut 1	Class 140	196 per pile	98 per pile
Bent 2	Class 200 Pile Group OR 60 in. Diameter CIDH Column Shaft	280 per pile OR 1850 per column	0
Bent 3	30 in. CIDH Pile Group OR 60 in. Diameter CIDH Column Shaft	380 per pile OR 1950 per column	0
Abut 4	24 in. CIDH	280 per pile	140 per pile

Notes:

1. Typically, Extreme Event Limit State loads are unknown for preliminary design. Provide that information only where large tension pile loads are anticipated (i.e., overstrength plus overturning effects). The geoprofessional should be aware of the possibility of large tension loads, so that appropriate pile types can be recommended when evaluating foundation type, assessing drivability, etc.
2. At the preliminary stage, an estimate of maximum factored loads is not required for standard piles; rather, provide Factored Nominal Structural Resistance.
3. Maximum factored loads are estimated based on Strength load combinations. The geoprofessional will use the applicable φ factor for the Strength load combinations.

The request for a Foundation Report is prepared after preliminary structural analysis and includes tables that provide scour data (Table 10.7.A3-2), general foundation information in the *Foundation Design Data Sheet* shown in Table 10.7.A3-3 (Table 4 of BD-0304), and governing loads for different LRFD Limit States as shown in Table 10.7.A3-4 (Table 5 of BD-0304). The increase in axial force of the piles caused by static and seismic drag load (DR) shall be considered in the analysis.

Table 10.7.A3-2: Scour Data

Support No.	Long Term (Degradation and Contraction) Scour Elevation (ft)	Short Term (Local) Scour Depth (ft)
Abut 1		
Pier 2		
Pier 3		
Abut 4		

Table 10.7.A3-3, Foundation Design Data Sheet

Support Location	Pile Type	Finished Grade Elevation (ft)	Cut-off Elevation (ft)	Pile Cap Size (ft)		Permissible Settlement under Service Load* (in)	Number of Piles per Support
				B	L		
Abut 1						1" or 2"	
Bent 2						1" or 2"	
Bent 3						1" or 2"	
Abut 4						1" or 2"	

* Refer to AASHTO-CA BDS Article 3.4.1 for permissible settlements under service loads and settlement load factor.

Table10.7.A3-4. Foundation Factored Design Loads

Support No.	Service-I Limit State Net Load per Support (kips)		Strength Limit State Gross Loads (kips)				Extreme Event Limit State Gross Loads (kips)			
	Total Load	Permanent Load	Compression		Tension		Compression		Tension	
			Per Support	Max. Per Pile	Per Support	Max. Per Pile	Per Support	Max. Per Pile	Per Support	Max. Per Pile
Abut 1										
Bent 2										
Bent 3										
Abut 4										

Notes:

1. For pile extensions and Type-I shafts, the pile/shaft loads shall be calculated at finished grade elevation. For column shafts (Types I and II) both "load per support" and "load per pile/shaft" refer to load at the base of the column.
2. When seismic down-drag conditions exist, the maximum permanent load per pile will be provided to the geoprofessional.

At final design, the geoprofessional includes foundation recommendations in the Foundation Report (FR) in accordance with the Foundation Reports for Bridges in the Geotechnical Manual. Two tables are presented in the foundation recommendations section of the report: the Foundation Design Recommendations table and the Pile Data Table. The Pile Data Table, once finalized, is shown in the contract plans.

The following information is used in preparation of the foundation design recommendations and pile data tables:

1. The required nominal geotechnical resistance is shown for all piles, regardless of pile type or acceptance criteria. The nominal resistance is rounded up to the nearest 10 Kips.
2. The cut-off elevation is required in the Pile Data Table whenever it cannot be calculated from the bottom of footing elevation and pile head embedment shown on the plans. Mined shafts, column shafts, and pile extensions, which have no footings, require a cut-off elevation in the Pile Data Table.
3. The design tip elevations for compression, tension, lateral, and settlement are shown on the plans when the information is required by design/construction for pile/shaft acceptance. These elevations express the "intent" of the design and help the field engineer to resolve constructability and quality issues. When the lateral tip elevation determined by SD is the lowest design tip elevation, the geoprofessional needs to update the Foundation Report, including the Foundation Recommendations Table (10.7.A3-5) and the Pile Data Table (10.7.A3-6).
4. The specified tip elevation is the controlling (deepest) value of the design tip elevations.
5. The specified tip elevation shall not be raised above the design tip elevations for tension, lateral, and, in some cases, for tolerable settlement without the consent of the geoprofessional.
6. The values of geotechnical resistance factors (φ) used in the following examples are explanatory. These factors are provided by geoprofessional.

The information to be provided to the SD to complete substructure design, as well as information to be shown in pile data tables of the plans, will be explained through the following examples. The geoprofessional provides design and specified pile tip elevations as well as "Nominal Geotechnical Resistance" of the piles and corresponding "Geotechnical Resistance Factors". The SD should check the information and finalize the pile data table to be shown in the plans.

The following examples have been added to clarify the information needed. Refer to *Caltrans Seismic Design Criteria* (SDC) for soil classification (classes S1 and S2).

- Example #1 – Standard Plan Piles, CIDH Piles, and CISS Piles in Class S1 Soil Profile.
- Example #2 – CIDH Piles with Permanent Steel Casing in Class S2 Soil with Seismic Downdrag

- Example #3 – Large Diameter CIDH Piles with Permanent Steel Casing (Seismic Retrofit)

Example 1) Standard Plan Piles, CIDH Piles, and CISS Piles in Class S1 Soil

A three-span overcrossing with single column bents and seat-type abutments is constructed in Class S1 soil per SDC classification. Standard Plan Class 140 piles will be utilized at the abutments, 24" CISS piles at Bent 2, and 42" CIDH piles at Bent 3. Use of different types of piles at bents is usually avoided in practice. In this example, different piles were assumed to illustrate the information required for each case.

Table 10.7.A3-5 shows an example of information provided by the geoprofessional for abutments and bents. However, design tip elevations for lateral loads are determined by the SD and will be added to Table 10.7.A3-6. Resistance factors (φ) for Strength and Extreme Event load combinations are also given in Table 10.7.A3-5. Nominal tip resistance is only shown for CIDH piles (in parenthesis). Typical footnotes shown under the tables are project specific and will be included in the FR and Pile Data Table for clarification.

Table 10.7.A3-5. Foundation Design Recommendations

Support Location	Pile Type	Cut-off Elevation (ft)	Service-I Limit State Load per Support (kips)		Total Permissible Support Settlement (inches)	Required Nominal Resistance per Pile, kips (Nominal Tip Resistance, kips)				Design Tip Elevations (ft)	Specified Tip Elevation (ft)	Required Nominal Driving Resistance (kips)
						Strength		Extreme Event				
			Total	Permanent		Comp.	Tension	Comp.	Tension			
Abut. 1	Class 140 (Alt. "X")	72	1340	1040	1	280	0	N/A	N/A	30(a-I) 31(c) 34(d)	30	280
Bent 2	CISS 24x0.5	59	1750	1380	1	**382**	180	**365**	165	6 (a-I) 12(b-I) 9 (a-II) 18(b-II) 15(c) 9(d)	6	420
Bent 3	42" CIDH	64	2250	1750	1	407 (0)	173	**380** **(0)**	186	6(a-I) 12(b-I) 9(a-II) 12(b-II) 3(c) 15(d)	3	N/A
Abut. 4	Class 140 (Alt. "X")	78	1260	870	1	260	0	N/A	N/A	32(a-I) 31(c) 34(d)	31	280

Notes:

1) Geotechnical resistance factors φ_{qs} and φ_{qp} are used for side resistance and tip resistance, respectively. The following geotechnical resistance factors for tension and compression (Strength limit state load combinations) have been used:
   Driven piles (including CISS): φ_{qs} = 0.7, φ_{qp} = 0.7
   CIDH piles: φ_{qs} = 0.7, φ_{qp} = 0.5
   All geotechnical resistance factors for the Extreme Event limit state are 1.0.
2) Design tip elevations are controlled by: (a-I) Compression (Strength Limit), (b-I) Tension (Strength Limit), (a-II) Compression (Extreme Event), (b-II) Tension (Extreme Event), (c) Settlement, (d) Lateral Load (where applicable).
3) The specified tip elevation of driven piles shall not be raised above the design tip elevations for tension, lateral, and permissible settlement.

Notes cont.:

4) The CIDH specified tip elevation shall not be raised.
5) The required nominal driving resistance is equal to the nominal resistance needed to support the factored loads plus driving resistance from the unsuitable penetrated soil layers (very soft, liquefiable, scourable, etc.), if any, which do not contribute to the design resistance. Unsuitable soil layers at Bent 2 and Abutment 4 extend to elevations of 48 ft., and 65 ft., respectively.
6) Design tip elevation for Lateral Load is provided by the SD.

Table 10.7.A3-6 shows the foundation information that the SD shows on the contract plans. The SD verifies that factored geotechnical nominal resistance values are equal to or greater than factored loads for different combinations.

The required nominal geotechnical resistance values of Strength and Extreme Event combinations are compared, and the largest values for both tension and compression are selected and rounded up to nearest 10 kips as shown in Table 10.7.A3-6. Design tip elevations are compared and the lowest elevation will be shown as specified tip elevation in the Pile Data Table.

Table 10.7.A3-6. Pile Data Table

Location	Pile Type	Nominal Resistance (kips)		Design Tip Elevation (ft)	Specified Tip Elevation (ft)	Required Nominal Driving Resistance (kips)
		Compression	Tension			
Abut. 1	Class 140 Alt. "X"	280	0	30(a), 31(c), 34(d)	30	280
Bent 2	CISS 24x0.5	390	180	6 (a), 12(b), 15(c), 9(d)	6	420
Bent 3	42" CIDH	410	190	6 (a), 12(b), 3 (c), 15(d)	3	N/A
Abut. 4	Class 140 Alt. "X"	260	0	32(a), 31(c), 34(d)	31	280

General Notes:

1) Design tip elevations for Bents and Abutments are controlled by: (a) Compression, (b) Tension, (c) Settlement, (d) Lateral Load
2) The specified tip elevation shall not be raised above the design tip elevations for tension load, lateral load, and permissible settlement.

Example 2) CIDH Piles with Permanent Steel Casing in Type S2 Soil with Seismic Downdrag

The following example shows foundation recommendations and the Pile Data Table for a typical multi-column under-crossing bent (pinned footings) constructed in Class S2 soil (per SDC classification) with possibility of seismic downdrag. Drilled shafts with permanent steel casing will be used at the bent. The purpose of permanent steel casing is mainly to facilitate construction. The permanent steel casing does not contribute to geotechnical resistance however it may contribute to structural resistance. In addition to information given in Table 10.7.A3-5, the geoprofessional will also provide the casing specified tip elevation as shown in Table10.7.A3-7. The casing specified tip elevation will be also shown in the Pile Data Table (Table10.7.A3-8). Tables 10.7.A3-7 and 10.7.A3-8 will be provided by the geoprofessional. Design tip elevation for lateral load should be provided by SD to be included in FR.

Table 10.7.A3-7. Foundation Design Recommendations

Support Location	Pile Type	Cut-off Elevation (ft)	Service-I Limit State Load per Support (kips)		Total Permissible Support Settlement (inches)	Required Nominal Resistance per Pile, kips (Nominal Tip Resistance, kips)					Design Tip Elev. (ft)	Specified Tip Elevation (ft)	Steel Casing Specified Tip Elevation (ft)
						Strength Limit State		Extreme Event Limit State					
			Total	Permanent		Comp.	Tension	Comp.	Comp. with Downdrag	Tension			
Bent 2	48 in. CIDH piles with 60 in. permanent steel casing	85	2670	2150	1	491 (124)	76	389 (124)	450 (124)	118	25 (a-I) 29(b-I) 30(a-II) 27(b-II) 31(a-III) 24 (c) 26(d)	24	40

Notes:

1) Geotechnical resistance factors φ_{qs} and $\varphi_{qp}$are used for side resistance and tip resistance, respectively. The following geotechnical resistance factors for tension and compression (Strength limit state load combinations) have been used:
$\varphi_{qs} = 0.7$, $\varphi_{qp} = 0.5$. All geotechnical resistance factors for the Extreme Event limit state are 1.0.
2) Design tip elevations are controlled by: (a-I) Compression (Strength Limit), (b-I) Tension (Strength Limit), (a-II) Compression (Extreme Event), (a-III) Compression (Extreme Event-Downdrag), (b-II) Tension (Extreme Event), (c) Settlement, (d) Lateral Load
3) The CIDH specified tip elevation shall not be raised.
4) Nominal tip resistance of CIDH piles is shown in parenthesis (when applicable).
5) For "Compression with Downdrag" of Extreme Event I limit state, calculate axial forces of the piles based on combination of the maximum permanent load plus downdrag. This case is applicable when soil liquefaction-induced downdrag is present.
6) Geoprofessional provides top and bottom elevations of the zone with downdrag forces acting on the pile, as well as total downdrag force per pile.

Table 10.7.A3-8. Pile Data Table

Location	Pile Type	Nominal Resistance (kips)		Permanent Steel Casing Specified Tip Elevation (ft)	Design TipElevation (ft)[1]	Specified TipElevation (ft)[2]
		Compression	Tension			
Bent 2	48 in. CIDH piles with 60 in. permanent steel casing	500	120	40	25 (a) 27(b), 24(c) 26(d)	24

General Notes:

1) Design tip elevations are controlled by: (a) Compression, (b) Tension, (c) Settlement, (d) Lateral Load,
2) The CIDH specified tip elevation shall not be raised.

Example 3) Large Diameter CIDH Piles with Permanent Steel Casing (Seismic Retrofit)

The following example is the seismic retrofit of a major river crossing bridge in Type S2 soil per SDC classification (negligible seismic downdrag) where a large diameter CIDH pile with permanent steel casing is recommended. Permanent steel casing increases the pile lateral stiffness and nominal structural resistance. For seismic retrofit projects, only Extreme Event-I loads are provided to the geoprofessional. Table 10.7.A3-9 shows foundation design recommendations provided by the geoprofessional. Table 10.7.A3-10 shows pile data table to be shown on the plans.

Table 10.7.A3-9. Foundation Recommendations for Bents

Support Location	Pile Type	Cut-off Elevation (ft)	Required Nominal Resistance for Extreme Event Limit State per Pile, (kips)				Steel Casing Specified Tip Elevation (ft)	CIDH Design Tip Elevations (ft)	CIDH Specified Tip Elevation (ft)
			CIDH Pile		Steel Casing				
			Compression	Tension	Compression	Tension			
Bent 2	60 in. CIDH piles with 72x0.75" Permanent Steel Casing	16	1112	472	0	0	-30	-51 (a-II) -46 (b-II) -48 (d)	-51

Notes:

1) Design tip elevations are controlled by: (a-II) Compression (Extreme Event), (b-II) Tension (Extreme Event), (d) Lateral Load
2) The CIDH specified tip elevation shall not be raised.

Table 10.7.A3-10. Pile Data Table

Location	Pile Type	Nominal Resistance (kips)		Nominal Resistance (Steel Casing) (kips)		Steel Casing Specified Tip Elevation (ft)	CIDH Design Tip Elevation (ft)	CIDH Specified Tip Elevation (ft)
		Comp.	Tension	Comp.	Tension			
Bent 2	60 in. CIDH piles with 72x0.75" Permanent Steel Casing	1120	480	0	0	-30	-51 (a) -46 (b) -48 (d)	-51

General Notes:

1) Design tip elevations are controlled by: (a) Compression, (b) Tension, (d) Lateral Load
2) The CIDH specified tip elevation shall not be raised.