Cast-In-Drilled-Hole (CIDH) Pile Foundations for Bridges

This document presents the design methods and communication steps between Structure Design (SD) and Geotechnical Services (GS) for the load and resistance factor design (LRFD) of Cast-In-Drilled-Hole (CIDH) pile foundations used for support of bridges, retaining walls, non-standard walls, signs, and other structures.

Also included in this module are three appendices:

- Appendix 1: Design Example: Cohesionless and Cohesive soils with Scour, Liquefaction and Downdrag
- Appendix 2: Design Example: Rock
- Appendix 3: Design Example: Intermediate Geo Material (IGM)

When a request for foundation design has been sent by SD to GS, the Geoprofessional assigned the project must review the request and make sure that the information provided is sufficient to understand the scope of the project, and adequate to initiate the design process.

Design of a CIDH pile foundation is a process that requires communication and data exchange between the Structure Designer and the Geoprofessional. The process presented in this module begins when the choice of a CIDH pile foundation has been made and after adequate subsurface site data has been obtained.

The reference policies and advisories for CIDH pile foundation investigations, design, and reporting are:

- Caltrans Seismic Design Criteria (SDC)
- AASHTO LRFD Bridge Design Specifications with CA Amendments (AASHTO)
- Drilled Shafts: Construction Procedures and Design Methods (O’Neill & Reese, 1999)
- Caltrans Standard Specifications, Standard Plans, Bridge Standard Detail Sheets (XS Sheets)
- Bridge Memos to Designers (MTD)
  - MTD 1-35, Foundation Recommendations and Reports
  - MTD 3-1, Deep Foundations
- Bridge Design Aids
- Bridge Construction Records and Procedures Manual, Volume II
- Caltrans Geotechnical Manual
  - Communication and Reporting
  - Foundation Reports for Bridges
  - Geotechnical Investigations
Geotechnical Service’s role in CIDH pile foundation design is to provide the Structure Designer with a foundation report addressing the following:

- The Controlling Design Tip Elevation.
- The Steel Casing Specified Tip Elevation (if applicable).
- Relevant design and construction considerations.

The Structure Designer’s role in deep foundation design must include, but not limited to:

- Providing the project schedule including due dates for reports.
- Providing GS the foundation design data and factored design load information. It is essential that any revised design parameters be communicated by SD to GS as soon as that information is developed.
- Providing GS the latest plan sheets pertinent to foundation design (e.g. General Plan, Foundation Plan, Foundation Detail Sheets, etc).

**Investigations**

The goal of the geotechnical investigation for a CIDH pile foundation is to determine the properties and behaviors of the soil and/or rock, and the groundwater condition that can affect foundation design and construction. All subsurface conditions that might influence the foundation design and performance should be investigated.

The Geoprofessional should perform a literature search to gather all relevant information related to site geology, strength of soil and rock, and geologic hazards. Refer to the *Geotechnical Investigations* module for direction on performing a literature search.

The Geoprofessional should develop a prudent exploration plan considering site constraints, geologic variability, and available resources. Borings should be located as close as possible to the proposed foundation.

The exploration plan should include:

- An appropriate number of exploratory borings and/or cone penetration tests (CPT) to develop the design soil profile (AASHTO Table 10.4.2-1).
- An appropriate depth of exploration for the borings or CPT. The depth of exploration should generally extend below the anticipated pile tip elevation a minimum of 20 feet, or a minimum of two times the maximum pile group dimension, whichever is deeper (AASHTO Table 10.4.2-1).
- Standard penetration tests (SPT). When SPTs are to be performed, sampling intervals should be limited to no more than 5 feet.
- Groundwater measurements.
• Soil and water samples for corrosion testing in accordance with current *Caltrans Corrosion Guidelines*.

• Adequate samples for laboratory testing (e.g. classification tests, consolidation test, soil strength parameters required for design).

**Design Methodology**

The following provides design methodology used for calculating settlement (Service-I Limit State) and pile resistance (Strength and Extreme Event Limit States) in accordance with AASHTO 10.8.1. For appropriate resistance factors refer to AASHTO Table 10.5.5.2.4-1.

The soil properties used in design should come from: (1) SPT correlations (see *Correlations Module*) and/or (2) results of laboratory tests under similar field conditions. However, engineering judgment should be used in case of inconsistency of field and laboratory data.

The design must also account for geologic hazards such as:

- Liquefaction, lateral spreading
- Landslides
- Scour: Foundations that are constructed in a watercourse must meet AASHTO guidelines regarding scour depths (AASHTO CA Amendments C2.6.4.4-2). The top of the pile cap must be below the degradation plus contraction scour depth. The bottom of the pile cap must be below the degradation plus contraction plus local pier scour depth.

**Design Information and Communication**

After the field investigation and testing has been completed, the Geoprofessional will need to review the design information provided by the Structure Designer which should include:

- General Plan
- Foundation Plan
- Scour Data Table (if scour potential exists, MTD 3-1, Attachment 1) or Hydraulics Report
- Foundation Design Data Sheet (MTD 3-1, Attachment 1, also below)
- Foundation Factored Design Loads information (MTD 3-1, Attachment 1, also below)
### Table X: Foundation Design Data Sheet (MTD 3-1, Attachment 1)

<table>
<thead>
<tr>
<th>Support No.</th>
<th>Pile Type</th>
<th>Finished Grade Elevation (ft)</th>
<th>Cut-off Elevation (ft)</th>
<th>Pile Cap Size (ft)</th>
<th>Permissible Settlement under Service Load (in)</th>
<th>Number of Piles per Support</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abut 1</td>
<td>30-in diam. CIDH</td>
<td>2470.0</td>
<td>2462.0</td>
<td>17</td>
<td>51</td>
<td>26</td>
</tr>
<tr>
<td>Pier 2</td>
<td>96-in diam. CIDH</td>
<td>2454.0</td>
<td>2452.0</td>
<td>N/A</td>
<td>N/A</td>
<td>1</td>
</tr>
<tr>
<td>Abut 3</td>
<td>30-in diam. CIDH</td>
<td>2480.0</td>
<td>2471.0</td>
<td>17</td>
<td>51</td>
<td>26</td>
</tr>
</tbody>
</table>

### Table X: Foundation Factored Design Loads (MTD 3-1, Attachment 1)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total Load per Support</td>
<td>Compression Per Support/Max. Per Pile</td>
<td>Tension Per Support/Max. Per Pile</td>
</tr>
<tr>
<td></td>
<td>Permanent Load per Support</td>
<td>Compression  Per Support/Max. Per Pile</td>
<td>Tension Per Support/Max. Per Pile</td>
</tr>
<tr>
<td>Abut 1</td>
<td>2696</td>
<td>4590/267</td>
<td>0/4.0</td>
</tr>
<tr>
<td></td>
<td>2345</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pier 2</td>
<td>4090</td>
<td>5605/5605</td>
<td>0/0</td>
</tr>
<tr>
<td></td>
<td>3425</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abut 3</td>
<td>2920</td>
<td>4938/330</td>
<td>0/53.0</td>
</tr>
<tr>
<td></td>
<td>2598</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Design Process

Complete the CIDH pile foundation design process by following the steps below:

**Step 1: Evaluation of Support Location and Foundation Type**
- Verify that the foundation location and type is acceptable considering the known subsurface information and geological hazards (e.g., scour, lateral spreading, liquefaction).

**Step 2: Calculate the Design Tip Elevations for the Piles**
- Calculate the design tip elevations meeting the controlling compression and tension requirements for the Strength Limit State and the Extreme Event Limit State at each support location.
• Calculate the design tip elevations meeting the permissible settlement criteria for Service-I Limit State. (Commentary: Pile design should ensure that strength limit state considerations are satisfied before checking service limit state considerations. For piles embedded adequately into dense granular soils such that the equivalent footing is located on or within the dense granular soil, and furthermore are not subjected to downdrag loads, a detailed assessment of the pile group settlement may be waived. If the design tip for service limit state is waived, then a note should be placed at the bottom of the pile data table).

• Using the design tip elevation from Strength or Extreme Limit State, verify the settlement under the Service-I Limit State load is less than the permissible settlement.

Step 3: Determine the Controlling Design Tip Elevation

• The deepest design tip elevation in compression, tension, and settlement determined by Geotechnical Services will be the controlling design tip elevation, and shown in the Foundation Design Recommendations and Pile Data Tables. The Structure Designer will need to compare their design tip elevation for lateral loading to the GS Controlling Design Tip Elevation. The lowest elevation will become the final Specified Tip Elevation to be shown on the contract plans.

Step 4: Determine the Specified Tip Elevation for the Steel Casing (if applicable).

(Commentary: Depending on the method of excavation, the diameter of the rock socket may need to be sized at least 6 inches smaller than the nominal casing size to permit seating of casing and insertion of rock drilling equipment (AASHTO 2012, C10.8.1.3).

Step 5: Provide Foundation Recommendations Table and Pile Data Table

• Fill out the Foundation Recommendations Table and the Pile Data Table (MTD 3-1, Attachment 1, also below) with the applicable information, and include in the Foundation Report.
### Table X: Foundation Design Recommendations

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Strength Limit</td>
<td>Extreme Event</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Comp. ((\psi_s=0.7)) ((\psi_p=0.5))</td>
<td>Tension ((\psi_s=0.7))</td>
<td>Comp. ((\psi_s=1)) ((\psi_p=1))</td>
<td>Tension</td>
<td></td>
</tr>
<tr>
<td>Abutment 1 30-inch Dia. CIDH</td>
<td>2462.0</td>
<td>2700 kips</td>
<td>2350 kips</td>
<td>1 in</td>
<td>470 kips</td>
<td>10 kips</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Pier 2 96-inch Dia. CIDH</td>
<td>2452.0</td>
<td>4090 kips</td>
<td>3800 kips</td>
<td>1 in</td>
<td>9080 kips</td>
<td>0 kips</td>
<td>3430 kips</td>
<td>0 kips</td>
<td>N/A</td>
</tr>
<tr>
<td>Abutment 3 30-inch Dia. CIDH</td>
<td>2471.0</td>
<td>2920 kips</td>
<td>2600 kips</td>
<td>1 in</td>
<td>580 kips</td>
<td>80 kips</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Notes: Design tip elevations are controlled by (a-I) Compression (Strength Limit), (a-II) Compression (Extreme Event), (b-I) Tension (Strength Limit), (c) Settlement, (d) Lateral Load

1) Resistance factor \(\psi_s\) is for skin friction, and \(\psi_p\) is for end-bearing

2) Lateral Load design tip elevations (d) were provided by the Structure Designer

### Table X: Pile Data Table

<table>
<thead>
<tr>
<th>Location</th>
<th>Pile Type</th>
<th>Nominal Resistance</th>
<th>Top of Rock Socket Elevation</th>
<th>Design Tip Elevation</th>
<th>Controlling Design Tip Elevation</th>
<th>Steel Casing Specified Tip Elevation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Compression Tension</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abutment 1 30-inch Dia. CIDH</td>
<td>470 kips</td>
<td>10 kips</td>
<td>N/A</td>
<td>2433.0 (a-I)</td>
<td>2439.0 (b-I)</td>
<td>2436.0 (c)</td>
</tr>
<tr>
<td>Pier 2 96-inch Dia. CIDH</td>
<td>9080 kips</td>
<td>0 kips</td>
<td>N/A</td>
<td>2395.0 (a-I)</td>
<td>2419.0 (a-II)</td>
<td>2422.0 (c)</td>
</tr>
<tr>
<td>Abutment 3 30-inch Dia. CIDH</td>
<td>580 kips</td>
<td>80 kips</td>
<td>N/A</td>
<td>2445.0 (a-I)</td>
<td>2452.0 (b-I)</td>
<td>2448.0 (c)</td>
</tr>
</tbody>
</table>

Notes: Design tip elevations are controlled by (a-I) Compression (Strength Limit), (b-I) Tension (Strength Limit), (c) Settlement, (d) Lateral Load

1) Lateral Load design tip elevations (d) were provided by the Structure Designer

### Step 6: Relevant Design and Construction Considerations

- Any relevant design and construction considerations should be communicated to the Structure Designer, and also presented in the Foundation Report as detailed in the Foundation Report for Bridges guidelines.

### Step 7: Reporting

- Once the design of the CIDH pile foundation is completed, the Geoprofessional may proceed with the process of finalizing the Foundation Report and issuing it to the client, per the Communication and Reporting module of the Geotechnical Manual.
Appendix 1: Design Example: Cohesionless and Cohesive Soils with Scour, Liquefaction and Downdrag

*(Design example under development)*

Appendix 2: Design Example: Rock

*(Design example under development)*

Appendix 3: Design Example: Intermediate Geo Material (IGM)

*(Design example under development)*