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

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 are the procedures for documenting design information that might be needed to evaluate the impact of an anomaly (i.e., construction defect), and related analytical procedures. The Appendices include three design calculation examples.

Standards relating to 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) 3-1, *Deep Foundations*
- Bridge Design Aids
- Bridge Construction Records and Procedures Manual, Volume II
- Caltrans Geotechnical Manual
  - *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:

- Design Tip Elevations for piles for Service, Strength and Extreme Event Limit State.
- The Controlling Design Tip Elevation.
- The Steel Casing Specified Tip Elevation (if applicable).
- Recommendations relating to specifications and construction.

The Structure Designer's role in CIDH pile design includes:

- Providing the project schedule including due dates for reports.
- Providing the foundation design data and factored design load information.
- Providing the latest plan sheets pertinent to foundation design (e.g. General Plan, Foundation Plan, Foundation Detail Sheets, etc).

Terminology

1. Cast-In-Drilled Hole (CIDH) concrete piles: CIDH concrete piles, also known as drilled shafts, can be used as smaller-diameter piles that are connected to a pile cap supporting a column or as a larger pile (typically 5 feet or larger) that directly supports a column and is either a Type I or Type II shaft (as determined by the Structure Designer). Standard Plan CIDH concrete piles are either 16 or 24 inches in diameter, whereas special design CIDH concrete piles range from 30 inches and greater. Piles placed in wet conditions must be at least 24 inches in diameter to accommodate inspection pipes for acceptance testing. CIDH concrete pile lengths should be limited to 30 times the pile diameter to help ensure constructability and quality.
    i. Type I Shaft: the reinforcement consists of one continuous cage that extends from the pile tip to the bent cap.
    ii. Type II Shaft: the reinforcement consists of one cage that extends from the pile tip to the pile cut-off elevation. The column cage is a smaller-diameter cage that extends into the CIDH concrete pile reinforcement cage to form a lap splice. For a 5-foot diameter or larger Type II shaft, a construction joint is mandatory at the bottom of the column rebar cage elevation. The construction joint requires the placement of a permanent steel casing/shell in the hole to allow workers to clean and prepare the joint.
2. Rock Socket: a pay item for the length of a CIDH concrete pile that is constructed in rock that requires a core barrel, cluster hammer, or other hard rock tool for excavation. The rock is usually stronger than concrete, and typically the side resistance is controlled by the compressive strength of concrete, not the rock strength.
3. Driven Steel Shell: Used for structural capacity and/or geotechnical resistance. Must be installed with an impact hammer.
4. Permanent Casing can be either:
    i. Permanent Smooth-wall Steel *Casing:* Used for constructability. May be used for structural capacity. Not used for geotechnical resistance. Unacceptable methods of installation must be listed in the Foundation Report, Notes for Specifications.
    ii. Corrugated Metal Pipe (CMP) *Casing:* Used for constructability. May be used for limited geotechnical resistance. Not used for structural capacity. A CMP is placed in an excavated hole and the annular space backfilled with grout (SS 49-3.02B(5), 49-3.02C(6)). If the conditions are dry, the geotechnical resistance of the CMP can be utilized in the pile design, however limit side resistance to the uppermost 20 feet.

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.

Perform a literature search (see *Geotechnical Investigations*) to gather all relevant information related to site geology, strength of soil and rock, and geologic hazards. Then, 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

The following provides design methodologies used to calculate 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.

Soil properties used for design should come from: (1) SPT correlations (see *Soil Correlations* module) and/or (2) results of laboratory tests under similar field conditions.

The design must also account for geologic hazards such as:

- Liquefaction (see *Liquefaction* module)
- Lateral spreading (see *Lateral Spreading* module)
- Scour: Foundations that are constructed in a watercourse must meet AASHTO guidelines regarding scour depths (AASHTO 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.

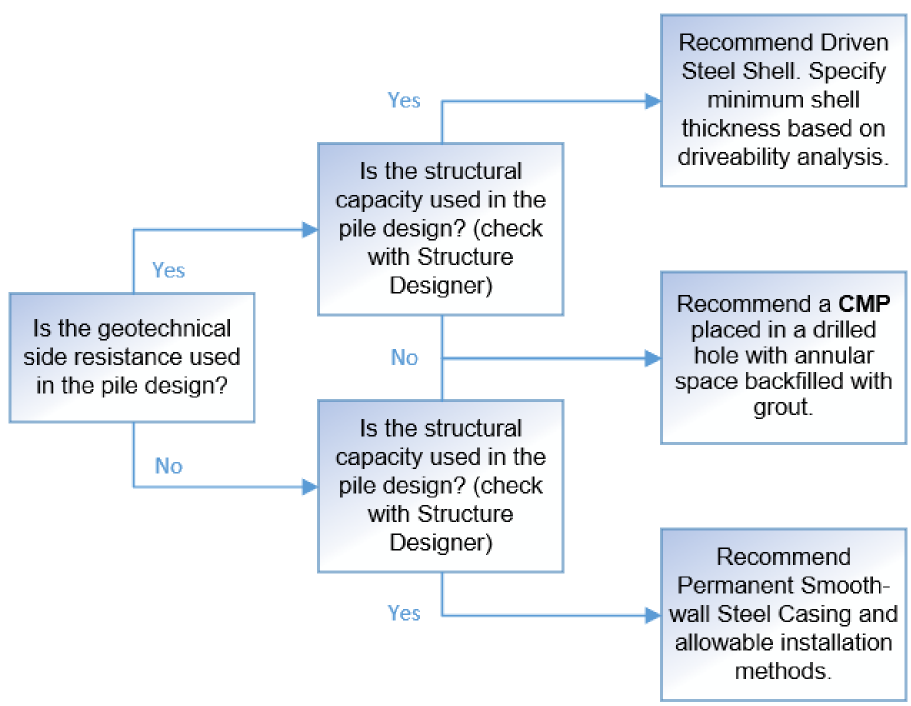
CIDH Concrete Pile Design Considerations

The following table presents options for selection of a permanent smooth-wall steel casing, driven steel shell, or CMP casing.

Permanent Smooth-wall Steel Casing, CMP, or Steel Shell in CIDH Concrete Pile Design

Types	Can it be used for Constructability?	Can it be used for Structural Capacity?	Can it be used for Geotechnical Resistance?	Installation Method
Permanent Smooth-wall Steel Casing	Yes	Yes	No	Drilled, vibrated, oscillated/rotated into place, or placed in drilled hole and annular space backfilled with grout
Corrugated Metal Pipe (CMP) Casing	Yes	No	No	Placed in a drilled hole and annular space backfilled with grout
Driven Steel Shell	Yes	Yes	Yes	Driven

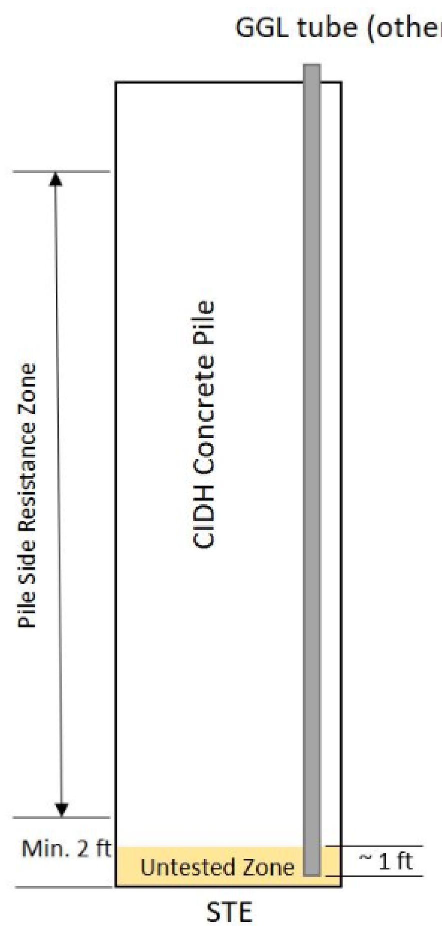
The flow chart shows the most cost-effective options for use of a permanent smooth-wall steel casing, shell or CMP.



Side Resistance Considerations

If it is anticipated that the slurry displacement method will be used for concrete placement, CIDH pile acceptance testing in accordance with California Test (CT) 233, "*Method of Ascertaining the Homogeneity of Concrete in CIDH Piles Using the Gamma-Gamma Test Method*" will be required. Due to the limitations of the gamma-gamma logging (GGL) equipment, there is a zone of untested concrete at the bottom the pile. To account for this zone of untested concrete, the specified tip elevation must be lowered a minimum of two feet below the bottom of the side resistance zone (Figure 1).

Figure 1: Untested Concrete Zone at Bottom of CIDH Pile



Tip Resistance Considerations

If the slurry displacement construction method is anticipated, tip resistance may be used in rock with certain considerations, as approved by the OGDPP.

Design Information and Communication (Preliminary Foundation Report)

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

- General Plan
- Preliminary Foundation Design Data Sheet (MTD 3-1, Attachment 1)

Table X: Preliminary Foundation Design Data Sheet

Support Location	Foundation Type(s) Considered	Estimate of Maximum Factored Compression Loads (Strength Limit State) (kips)
Abutment 1		
Pier 2		
Abutment 3		

Design Process (Preliminary Foundation Report)

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 Preliminary Tip Elevations

- Calculate the preliminary tip elevations meeting the controlling compression and tension requirements for the Strength Limit State at each support location.

Step 3: Complete Preliminary Foundation Design Recommendations table.

- Present the tip elevations for compression in the Preliminary Foundation Design Recommendations table under the Preliminary Tip Elevation column in the Preliminary Foundation Report.

Step 4: Reporting

- Complete the Preliminary Foundation Report according to the *Foundation Reports for Bridges* module.

Design Information and Communication (Foundation Report)

The Geoprofessional must review the design information provided by the Structure Designer, which should include:

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

Table X: Foundation Design Data Sheet (MTD 3-1, Attachment 1)

Support No.	Pile Type	Finished Grade Elevation (feet)	Cut-off Elevation (feet)	Pile Cap Size (feet)		Permissible Settlement under Service Load (inches)	Number of Piles per Support
				B	L		
Abut 1	30-in diam. CIDH						
Pier 2	96-in diam. CIDH			N/A	N/A		
Abut 3	30-in diam. CIDH						

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

Support No.	Service-I Limit State (kips)		Strength/Construction Limit State (Controlling Group, kips)				Extreme Event Limit State (Controlling Group, kips)			
	Total Load per Support	Permanent Load per Support	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							N/A	N/A	N/A	N/A
Pier 2										
Abut 3							N/A	N/A	N/A	N/A

Design Process (Foundation Report)

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: 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 8 inches smaller than the nominal casing size to permit seating of casing and insertion of rock drilling equipment (AASHTO 2017, C10.8.1.3).

Step 3: 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: Complete the Tables

- Present the tip elevations for compression, tension, and settlement in the Foundation Design Recommendations and Pile Data Tables.

Step 4: Prepare and Send Draft Foundation Report

- Complete the Draft Foundation Report according to the *Foundation Reports for Bridges* module.

Step 6: Determine the Specified Tip Elevation (Lateral Tip Considerations)

- Obtain the lateral tip elevation from the Structure Designer
    - If the lateral tip is higher than or equal to the specified tip elevation then there is no action required by the GP.
    - If the lateral tip is lower, the GP must verify that the pile can be installed to the lateral tip elevation and that all other recommendations in the report are correct (e.g., pile tip is now below groundwater, pile tip is now in rock).

Step 7: Reporting

- Complete the Foundation Report according to the *Foundation Reports for Bridges* module.

Design Data Documentation

If the contractor uses either the slurry displacement method to place concrete or temporary casing to aid in dewatering the drilled hole, the CIDH pile will be inspected in accordance with California Test (CT) 233, "*Method of Ascertaining the Homogeneity of Concrete in CIDH Piles Using the Gamma-Gamma Test Method*". If anomalies are detected in the pile, the Foundation Testing Branch will issue a *Pile Acceptance Report* stating that the pile be rejected. Geotechnical Services will then participate in a process, initiated by Structure Construction, to evaluate the impact of the anomaly on the pile's capacity and determine a path forward.

To meet the time requirements in the Standard Specifications for evaluating the effect of anomalies on the geotechnical capacity of CIDH piles, pertinent geotechnical design information must be readily accessible to the GP and BC. The following CIDH pile information must be retained in the Geotechnical Design Office's *Electronic Project File Storage System* (EPFSS).

- Foundation Report
- Log of Test Borings, (LOTB)
- Geological profile used for each CIDH pile design
- Soil and or rock strength parameters used in the design of each support/pile
- Calculations and/or computer/spreadsheet outputs used to determine each pile SPTE

Evaluation of Anomalous CIDH Concrete Piles

When a pile is rejected, the State has limited time per Standard Specification section 49-3.02A(4)(d)(iv) *Rejected Piles*, to determine which of the following options is available to the contractor:

1. The pile must be supplemented or replaced.
2. The pile must be repaired.
3. The pile is adequate with the anomaly left in place.

The *Pile Design Data Form* (PDDF) is used by Structure Construction with input by the Foundation Testing Branch, Structure Design, GS, and the METS Corrosion Branch to determine acceptable options for a rejected pile. The FTB will complete Part 1 of the PDDF, which will identify the location and extent of the anomaly, and attach the PDDF to the *Pile Acceptance Report*. A copy of the *Pile Acceptance Report* is sent to the Geoprofessional and the Chair of the CIDH Pile Mitigation Committee. SC will request that SD, GS and Corrosion complete their respective sections and return the PDDF to SC. The information completed by the FTB for Part 1 is used by the Geoprofessional to complete Part 2, SD to complete Part 3, and the Corrosion to complete Part 4 of the PDDF. See MTD 3-7, *Design Data Documentation and Evaluation of Anomalous Concrete Shafts,* for details.

The FTB produces a plot on the PDDF (Part 1) that identifies the top and the bottom of the anomaly and the percentage of the pile affected. Using the original design calculations and assumptions (found in the EPFSS), calculate:

- the area of the anomaly on the outside of the pile and the skin friction contribution of that area.

  <*Note: The geotechnical evaluation assumes that the anomaly does not affect the ability of the pile to transmit load to the pile below the anomaly*.>

- the area of the anomaly at the pile base and the end bearing contribution of that area.

If the required nominal resistance exceeds the anomaly-reduced nominal resistance, the pile is unacceptable. If the pile is determined to be adequate with the anomaly in place, then the contractor may either repair the pile and receive full payment or leave the anomaly in place and incur an administrative deduction as specified in the contract.

Complete Part 2 of the PDDF using the results of the analysis and return the form to SC.

If the capacity of the pile is determined to be inadequate by GS, SD or Corrosion, then the anomaly mitigation process will initiate and the FTB, SC, GS, and SD will collectively determine if the pile can be repaired, supplemented, or replaced. The standard repair techniques are excavation, removal and replacement for anomalous concrete near the top of the pile, or grouting repair to lower potions of the pile. If the standard repair methods are not feasible, SC will hold a *CIDH Pile Non-Standard Mitigation Meeting*, per *Bridge Construction Memo BCM 130-21* to determine an acceptable mitigation strategy.

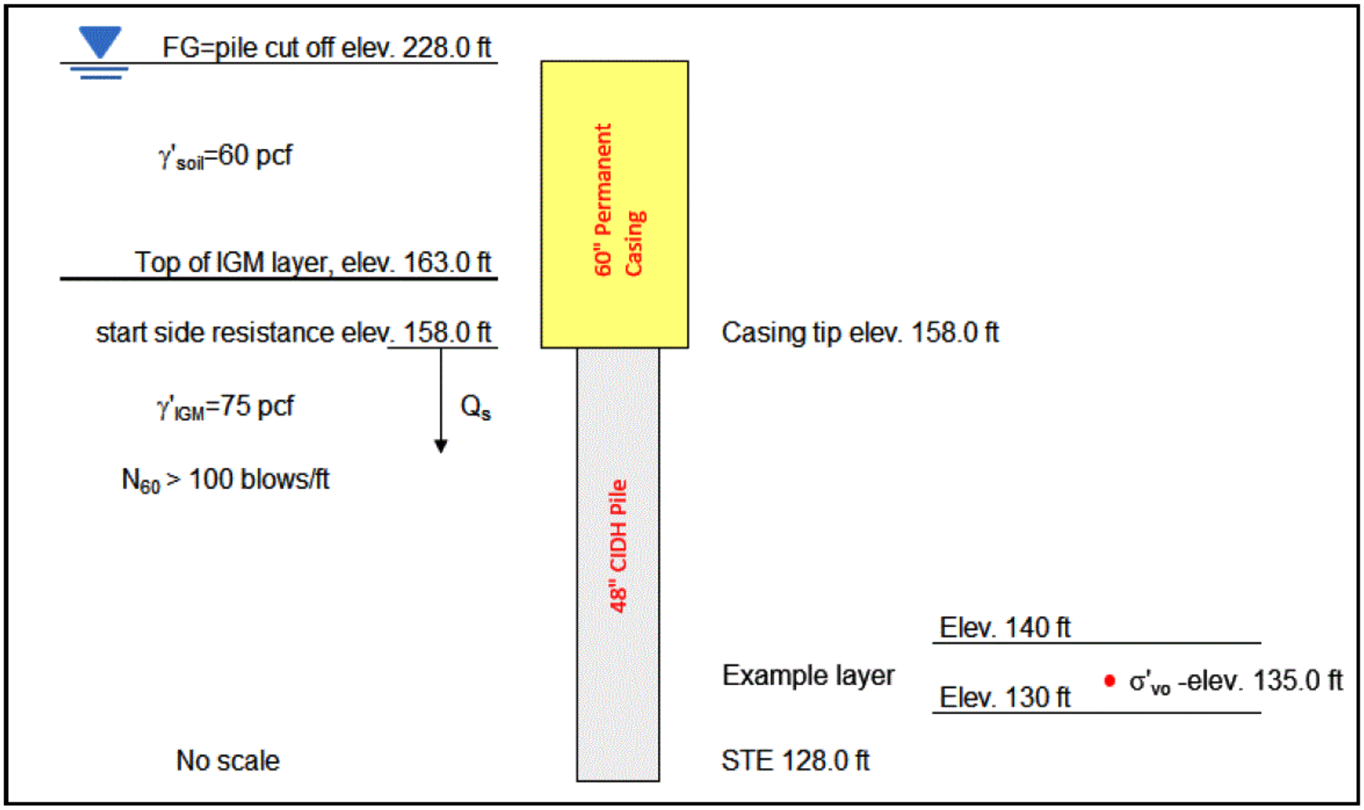
Attachments

- Appendix A: Example Design Calculations for Cohesionless IGM
- Appendix B: Example Design Calculations for Rock
- Appendix C: Example Calculations for Anomaly Evaluation Process

Appendix A: CIDH Pile Design in Cohesionless Intermediate Geomaterial (IGM)

The following presents the design calculations for a 10-foot layer (Elevation 140 feet to 130 feet) located at an abutment. Figure A1 shows the CIDH pile and soil/rock layers.

Figure A1: Simplified Soil/Rock Profile for Abutment 1 Design



<u>Information provided by Structure Design</u>

- 60-inch Permanent Steel casing is required.
- 48-inch CIDH pile (below casing tip).
- Controlling Factored Design Load = 1146 kips (Strength Limit State).
- The pile cutoff elevation is 228.0 ft.

<u>Geotechnical Design Considerations</u>

- The side resistance of the permanent casing is not used in the design.
- Due to the anticipation that concrete placement for the CIDH piles will require slurry displacement methods, the calculated geotechnical capacity of the piles is based on side resistance of 48-inch diameter CIDH piles and no tip resistance was considered. The design pile side resistance starts at elevation 158.0 ft.
- The required nominal resistance is factored design load divided by the resistance factor of side resistance or 1146 kips / 0.7 = 1637 kips, round up to 1640 Kips.

- Cohesionless IGM design method (for granular geomaterials with SPT N_{60} value greater than 50) will be used to determine pile side resistance.
- Based on the LOTB, representative N_{60} value of 100 was selected for cohesionless IGM design method. N_{60} values should be limited to 100 or less (O'Neill et al., 1996, p.32).
- Assume groundwater surface is at elevation 228.0 ft.

Step 1: Determine the Preconsolidation Pressure (σ'_p)

$$\sigma'_p = 0.2\ N_{60}\ \sigma_p$$

Where:

N_{60} = representative SPT blow count corrected for hammer efficiency effect

σ_p = atmospheric pressure taken as 2120 psf

$\boldsymbol{\sigma'_p} = 0.2 * 100 * 2120\ \text{psf} = \mathbf{42400}\ \text{psf}\ (N_{60} \leq 100)$

Step 2: Determine the Overconsolidation Pressure (OCR):

$$\text{OCR} = \frac{\sigma'_p}{\sigma'_{vo}}$$

Where:

σ'_{vo} = effective overburden pressure at mid layer

σ'_{vo} = (60 pcf)(elev. 228 ft -163 ft) + (75 pcf)(elev. 163 ft- 158 ft) + (75 pcf)(elev. 158 ft - 140 ft) + (75 pcf)(10 ft/2) = 6000 psf

$$\textbf{OCR} = \frac{42400\ \text{psf}}{6000\ \text{psf}} = \mathbf{7.07}$$

Step 3: Determine the Effective Friction Angle (ϕ'):

$$\phi' = \arctan\left\{\left[\frac{N_{60}}{12.2 + 20.3\left(\frac{\sigma'_{vo}}{\sigma_p}\right)}\right]^{0.34}\right\}$$

$$\phi' = \arctan\left\{\left[\frac{100}{12.2+20.3\left(\frac{6000\ \text{psf}}{2120\ \text{psf}}\right)}\right]^{0.34}\right\} = \mathbf{48.5^\circ}$$

Step 4: Determine the Coefficient of Horizontal Earth Pressure (K_o):

$$K_o = (1 - \sin\phi')\ OCR^{\sin\phi'}$$

$$\mathbf{K_o} = (1 - \sin(48.5°))7.07^{\sin(48.5°)} = \mathbf{1.086}$$

Step 5: Determine the Unit Side Resistance (q_s):

$$q_s = K_o \tan\phi'\ \sigma'_{vo}$$

As the "wet method" (slurry displacement method) is anticipated for the concrete placement, a reduction factor of 0.75 is applied to the effective internal friction angle, ϕ' (O'Neill et al., 1996, p.102).

$\mathbf{q_s} = (1.086)\tan(0.75 * 48.5°)\ 6000\ \text{psf} = \mathbf{4800\ psf}$ ("wet method")

Step 6: Determine the Side Resistance (R_s) *of the layer:*

$R_s = q_s\ \pi\ D\ L$

Where:

D = pile diameter

L = layer thickness

R_s = (4800 psf)(3.14)(4 ft)(10 ft) = 602880 lbs = **603 kips**

Table A1 presents side resistance values for the other IGM layers.

Table A1: Side Resistance

Bottom Elevation (feet)	Layer Thickness (feet)	γ' (pcf)	$\sigma'_{v(mid\ layer)}$ (psf)	N_{60}	σ'_p (psf)	OCR	Φ' (degrees)	K_o	q_s (psf)	R_s (kips)
158	70	0	4275[1]	0	0	0	0	0	0	0
150	8	75	4575	100	42400	9.27	50.6	1.27	4530	455
140	10	75	5250	100	42400	8.08	49.6	1.17	4663	586
130	10	75	6000	100	42400	7.07	48.5	1.09	4800	603

1: total overburden

Total = 1645 kips

Design Summary

Additional pile length should be added to the specified tip to account for the untested zone at bottom of pile. For this example, additional 2 ft was added to the required pile length.

Design Tip Elev. = 130 ft (from calculations)
- 2 ft (additional length for untested zone)

Specified Tip Elev. = 128 ft

Foundation Reports for Bridges Section 3.14.3, "Notes for Construction (CIDH Piles)" requires reporting of "*how the geotechnical resistance is derived*." Table A2 presents what would be reported for this example.

Table A2: CIDH Concrete Pile Side Resistance Zone Elevations

Support Location	Side Resistance Start Elevation (feet)	Side Resistance End Elevation (feet)	Specified Tip Elevation (feet)
Abutment 1	158.0	130.0	128.0

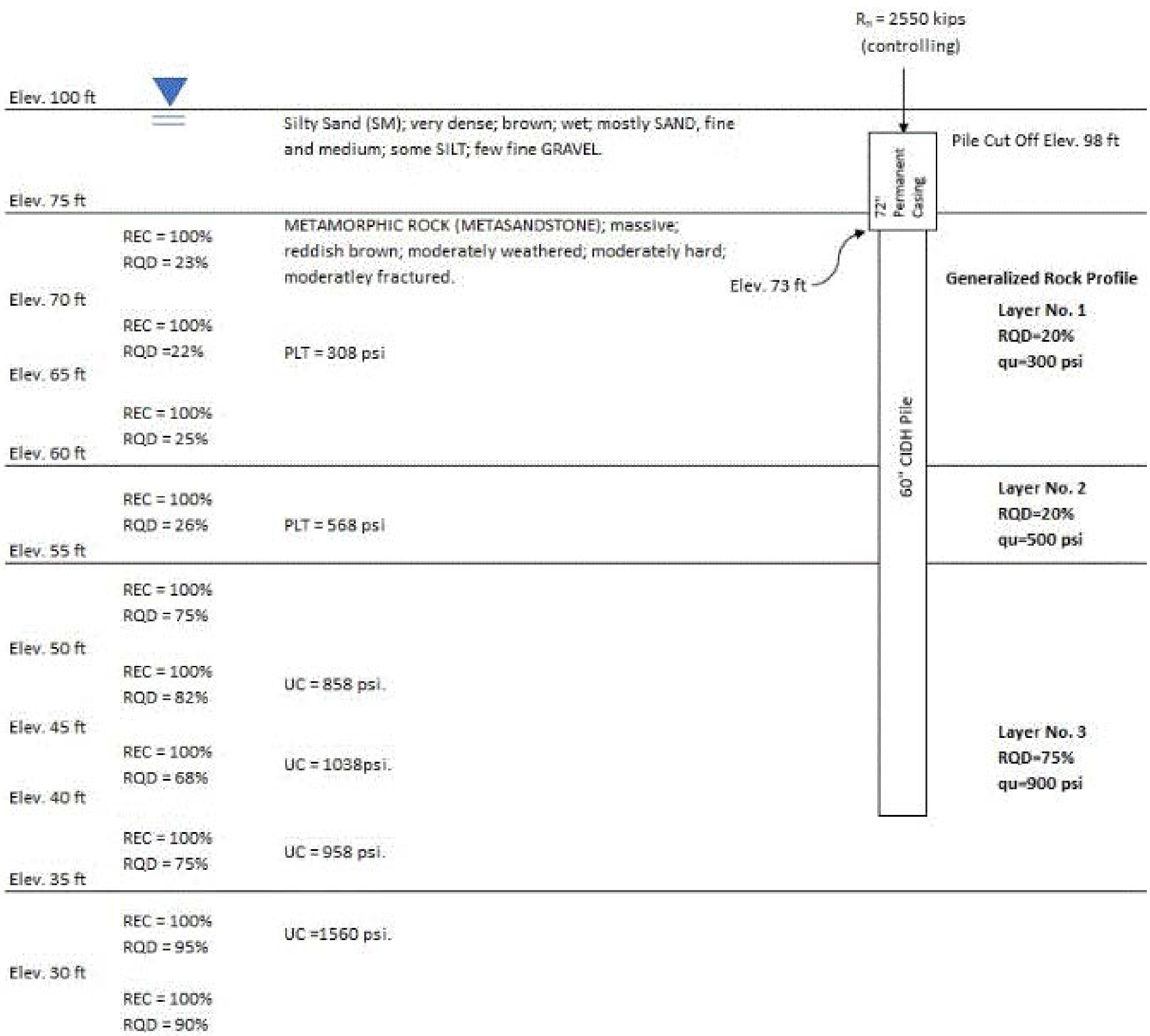
References

O'Neill M., Townsend F., Hassan, K., Buller, A, and Chan P., "Load Transfer for Drilled Shafts in Intermediate Geomaterials," FHWA-RD-95-172, Federal Highway Administration, McLean, VA, 1996

Appendix B: CIDH Pile Design in Rock

Appendix B presents the design calculations for a 60-inch diameter CIDH pile in rock located at Bent 2. Figure B1 shows the CIDH pile and soil/rock layers.

Figure B1: Simplified Soil/Rock Profile Design



<u>Information provided by Structure Design</u>

- 72-inch Permanent Steel casing is required.
- 60-inch CIDH pile (below casing tip).
- At Bent 2, the Controlling Factored Design Load = 1783 kips (Strength Limit State)
- The pile cutoff elevation is 98.0 ft.

Geotechnical Design Considerations

- The side resistance of 72-inch diameter permanent casing is not used in the design.
- Due to the anticipation that concrete placement for the CIDH piles will require slurry displacement methods, the calculated geotechnical capacity is based on side resistance of 60-inch diameter CIDH piles and no tip resistance was considered in this example.
- The controlling design load is 1783 kips (Strength Limit State). The required nominal resistance is 1783 kips /0.7 = 2547 kips, round up to 2550 Kips.
- The rock joints are closed.

Step 1: Determine the Factored Nominal Resistance (R_R)

$R_R = \varphi_{qp} R_p + \varphi_{qs} R_s$ (AASHTO 2017, 10.8.3.5-1)

Where:

R_p = nominal tip resistance

R_s = nominal side resistance

φ_{qp} = resistance factor for tip resistance

φ_{qs} = resistance factor for side resistance

Tip resistance is not used in this design example, therefore:

$R_R = \varphi_{qs} R_s$

Step 2: Determine the Unit Side Resistance (q_s) *of CIDH pile in rock*

Due to the low RQD values, assume temporary casing may be used during construction.

$\frac{q_s}{P_a} = 0.65\alpha_E \sqrt{\frac{q_u}{P_a}}$ (AASHTO 2017, 10.8.3.5.4b-2)

Where:

P_a = atmospheric pressure taken as 2.12 ksf

α_E = joint modification factor (AASHTO 2017, Table 10.8.3.5.4b-1)

q_u = uniaxial compressive strength of rock in ksf

Equation 10.8.3.5.4b-2 becomes:

$q_s = 0.946\alpha_E\sqrt{q_u}$ (q_s, q_u are in ksf)

$q_s = 2.5\alpha_E\sqrt{q_u}$ (q_s, q_u are in psi)

$q_s = 30\alpha_E\sqrt{q_u}$ (q_s, q_u are in psf)

Figure B2: AASHTO Table 10.8.3.5.4b-1

Table 10.8.3.5.4b-1—Estimation of α_E (O'Neill and Reese, 1999)

RDQ (%)	Joint Modification Factor, α_E	
	Closed Joints	Open or Gouge-Filled Joints
100	1.00	0.85
70	0.85	0.55
50	0.60	0.55
30	0.50	0.50
20	0.45	0.45

For Layer No. 1:

Representative rock properties from elev. 73 ft to elev. 60 ft:

RQD = 20 %, use α_E = 0.45 for closed joints.

q_u = 300 psi

Pile nominal side resistance, R_s, calculation:

$$q_s = 2.5\alpha_E\sqrt{q_u} = 2.5(0.45)\sqrt{300\text{psi}} = 19.5\text{ psi}$$

$$R_s = 19.5\text{ psi }(3.14)(60\text{ in})(\text{elev. }73\text{ ft} - \text{elev. }60\text{ ft})\left(\frac{12\text{ in}}{1\text{ ft}}\right)\left(\frac{1\text{ kip}}{1000\text{ lb}}\right) = 573\text{ kips}$$

If the RQD values are below 20% for most of the pile length, an alternative design method, such as the cohesionless Intermediate Geo Material method, should be used. Do not combine side resistances from IGM and rock design methods.

For Layer No. 2:

Representative rock properties from elev. 60 ft to elev. 55 ft:

RQD = 20 %, use α_E = 0.45 for closed joints

q_u = 500 psi

Pile nominal side resistance, R_s, calculation:

$$q_s = 2.5\alpha_E\sqrt{q_u} = 2.5(0.45)\sqrt{500\text{psi}} = 25.2 \text{ psi}$$

$$R_s = 25.2 \text{ psi } (3.14)(60 \text{ in})(\text{elev. } 60 \text{ ft} - \text{elev. } 55 \text{ ft})(\frac{12 \text{ in}}{1 \text{ ft}})(\frac{1 \text{ kip}}{1000 \text{ lb}}) = 285 \text{ kips}$$

For Layer No. 3:

Representative rock properties from from elev. 55 ft to elev. 35 ft:

RQD = 75 %, interpolate between RQD = 70% & 80% for α_E

$\alpha_E = 0.85 + \frac{(1.00-.85)}{(100-70)}(75-70) = 0.88$ for closed joints

q_u = 900 psi

Pile nominal side resistance, R_s, calculation:

$$q_s = 2.5\alpha_E\sqrt{q_u} = 2.5(0.88)\sqrt{900\text{psi}} = 66 \text{ psi}$$

Required Nominal Resistance at top of pile is 2550 kips. At top of layer no. 3, elev. 55 ft, the total pile side resistance is 573 kips + 285 kips = 858 kips. The pile design still needs 1692 kips (= 2550 kips – 858 kips) side resistance. Check for the minimum pile length (L_{min}) required in layer no. 3 to meet the 1692 kips in side resistance.

$$L_{min} = \frac{1692 \text{ kips}}{(66 \text{ psi})(3.14)(60 \text{ in})(\frac{12 \text{ in}}{\text{ft}})(\frac{1 \text{ kip}}{1000 \text{ lb}})} = 11.4 \text{ ft, say } 12 \text{ ft}$$

Design pile tip elevation is Elev. 55 ft -12 ft = 43 ft

Design Summary

Additional pile length should be added to the specified tip to account for the untested zone at bottom of pile. For this example, additional 2 ft was added to the required pile length.

Design Tip Elev. = 43 ft (from calculations)
- 2 ft (additional length for untested zone)

Specified Tip Elev. = 41 ft

Foundation Reports for Bridges Section 3.14.3, "Notes for Construction (CIDH Piles)" requires reporting of "*how the geotechnical resistance is derived*." Table A2 presents what would be reported for this example.

Table B1: CIDH Concrete Pile Side Resistance Zone Elevations

Support Location	Side Resistance Start Elevation (feet)	Side Resistance End Elevation (feet)	Specified Tip Elevation (feet)
Bent 2	73.0	43.0	41.0

Appendix C: Evaluating an Anomalous CIDH Concrete Pile

1. Assemble required design information, and the *Pile Acceptance Report*.
2. Report the Required Nominal Resistances shown in contract plans.
3. Determine the Remaining Required Nominal Resistance ($RRNR_{Ct}$ and $RRNR_{Tt}$) to be developed below the top of each anomalous section.
4. Determine the Remaining Required Nominal Resistance ($RRNR_{Cb}$ and $RRNR_{Tb}$) to be developed below the bottom of each anomalous section.
5. Determine and report the “as-designed” resistance over the entire pile surface from the top elevation to the bottom elevation of each anomaly.
6. Determine and report the calculated capacity loss in each of the anomalous lengths.
7. Report the soil and/or rock type.
8. Determine and report if each anomalous section is geotechnically acceptable.

If a pile has multiple anomalies and various combinations exist in a manner that some anomalies could be marked either “acceptable” or “unacceptable”, include a note in the *Comments* section of Part 2 of the PDDF that SD, GS, SC and Corrosion must discuss and develop a repair strategy.

If additional sources of resistance are available, they should be considered to contribute to the available resistance. These include:

- Tip resistance if not used in the pile design.
- Side resistance near the bottom of the pile not used in the pile design.
- Pile resistances increase~~s~~ due to reevaluation of the pile design calculations, e.g., the soil parameters may be reevaluated to see if using higher (but still realistic) values will result in increased nominal resistance.
- The structural designer may also check the actual demand of the anomalous pile. In pile groups the actual demands for interior piles may be considerably less than what is shown on the plans.
- The structural designer may accept additional settlement in lieu of the required capacity.

Definitions

Refer to Figure 2 for the following:

- R_{NC} = Nominal Resistance in compression.
- R_{NT} = Nominal Resistance in tension.
- STE = Specified Tip Elevation.
- Z_t = Side resistance zone start elevation.
- Z_b = Side resistance zone end elevation.
- AE_t **=** Top of anomaly elevation.

- AE_b **=** Bottom of anomaly elevation.
- L **=** Length of side resistance zone (Z_t - Z_b).
- $RRNR_{Ct}$ / $RRNR_{Tt}$ = Remaining Required Nominal Resistance at top of Anomaly for compression or tension, respectively
- $RRNR_{Cb}$ / $RRNR_{Tb}$ Remaining Required Nominal Resistance at bottom of Anomaly for compression or tension, respectively
- AF=Affected Pile Surface Area (%), see Part 1 of Pile Design Data Form.
- $R_{s\text{-}add}$ = Pile nominal resistance below the side resistance zone.

Example Calculations

Project Information

Bridge Name:	Deepwater Creek Bridge (Replace)
Bridge #:	53C-XXXX
Pile Diameter:	10 feet
Nominal Resistance:	R_{NC} = 6,600 kips
	R_{NT} = 0 kips
Pile Cutoff El.:	5.8 feet
Specified Pile Tip El.:	-133.0 feet
Ground Water El.:	2.31 feet

GGL Results (Figure C4)

Pile C at Bent 12 has two anomalous sections:
- Section A-A: Elevation 4.6 ft to 3.6 ft
- Section B-B: Elevation -10.8 ft to -16.0 ft

Geotechnical Design of Pile C at Bent 12

The Foundation reports states that:
- The geotechnical capacity of the CIDH pile is based on side resistance (R_s) only.
- The geotechnical capacity was calculated from one pile diameter (10 ft) below the pile cutoff elevation to one pile diameter (10 ft) above the STE.

Analysis Method

Step 1: Assemble and Review Pertinent Information

- From the *Pile Acceptance Report* and/or the PDDF (Figure 1) determine the location and size of anomalous zones.
  - Section A-A: from El. 4.6 ft to 3.6 ft
  - Section B-B: from El. -10.8 ft to -16.0 ft.
- Review the Foundation Report and calculations to determine where and how the geotechnical capacity was obtained. In this example, the geotechnical capacity is from skin friction only:

- Z_t = Pile Cutoff El. – One Pile Dia. = El. 5.8ft – 10ft = El. -4.2ft
- Z_b = SP~~T~~E + One Pile Dia. = El. -123.0 ft

- Plot Remaining Required Nominal Resistance vs. Elevation using the design calculations (Figure 4).

Step 2: Report Required Nominal Resistances Shown in Contract Plans

- Compression, R_{NC} = 6,600 kips
- Tension, R_{NT} = 0 kips.

Steps 3-6: Determine the "as-designed" nominal resistance over the entire pile surface from the top elevation to the bottom elevation of each anomaly and the calculated capacity loss within each anomaly length

(There is no tension demand in this example problem, therefore, there is no tension demand calculation shown.)

Anomaly A-A

Anomaly A-A is above the design side resistance and therefore does not reduce the CIDH pile's nominal capacity. Report the "as-designed" nominal resistance over the entire pile surface from the top elevation to the bottom elevation of each anomaly and the capacity loss within the anomaly length (kips), in Part 2 of the PDDF:

Section A-A: Compression: 0 / 0 Tension: 0 / 0

Anomaly B-B

Determine the "As-designed" Nominal Resistance as follows:

- $RRNR_{Ct} – RRNR_{Cb}$

  Where $RRNR_{Ct}$ = 6,600 - 367 Kips = 6,233 kips (Figure 4)

  $RRNR_{Cb}$ = 6,600 - 656 Kips = 5,944 kips (Figure 4)

- 6,233 kips – 5,944 kips = 289 kips (or 656 kips – 367 kips = 289 kips)

Calculate the capacity loss as follows:

- $(RRNR_{Ct} – RRNR_{Cb})$ x AF/100

  Where AF = 100% (Part 1 of PDDF, 12 of 12 inspection tubes)

- (6,233 - 5,944) x 100/100 = 289 kips

Anomaly B-B is within the design side resistance zone and therefore reduces the CIDH pile's nominal capacity.

Report the "as-designed" nominal resistance over the entire pile surface from the top elevation to the bottom elevation of each anomaly and the capacity loss within the anomaly length (kips), in Part 2 of the PDDF:

Section B-B: **Compression:** **289 / 289** **Tension:** **0 / 0**

Step 7: Report the soil and/or rock type

Using the LOTB (Figure C5), report the soil/rock type in the anomalous zone(s) in Part 2 of the PDDF:

Section A-A: **Soil and/or Rock Type:** **Silty Sand**

Section B-B: **Soil and/or Rock Type:** **Silty Sand and Fat Clay**

Step 8: Determine if each anomaly section is geotechnically acceptable

Anomaly A-A is located above the design side resistance zone and has no adverse impact on the geotechnical capacity of the CIDH pile. Check the appropriate boxes in the PDDF:

Section A-A: **Section is Geotechnically:** [X] **Acceptable** [ ] **Unacceptable**

Anomaly B-B results in a potential loss of 289 kips of side resistance. However, the geotechnical design of the pile did not include side resistance in the bottom 10 feet of the pile. This additional side resistance may be used to counter the capacity loss within the Anomaly B-B.

Determine the pile nominal resistance below the side resistance zone, from Elev. -123.0 ft to Elev. -133.0 ft.

$R_{s\text{-}add}$ = (7155-6600) = 555 kips

Because the excess of 555 kips is greater than the potential loss of 289 kips, the pile is considered to be acceptable. Check the appropriate boxes in the PDDF:

Section B-B: **Section is Geotechnically:** [X] **Acceptable** [ ] **Unacceptable**

Attachments

- Figure C1: Pile Design Data Form: Anomaly A-A
- Figure C2: Pile Design Data Form: Anomaly B-B
- Figure C3: Example Diagram
- Figure C4: GGL Plot
- Figure C5: Log of Test Borings (LOTB)

References

1. MTD 3-7 – Design Data Documentation and Evaluation of Anomalous Concrete Shafts (April 2012)
2. BCM 130-10 – Testing of CIDH Piling (June 2014)
3. BCM 130-20 – Cast-In-Drilled-Hole (CIDH) Pile Preconstruction Meeting (December 2011)
4. BCM 130-21 – CIDH Pile Non-Standard Mitigation Meeting (June 2014)
5. California Test (CT) 233 – Method of Ascertaining the Homogeneity of Concrete in Cast-In-Drilled-Hole (CIDH) Piles Using the Gamma-Gamma Test Method (November 2005)

Pile Design Data Form

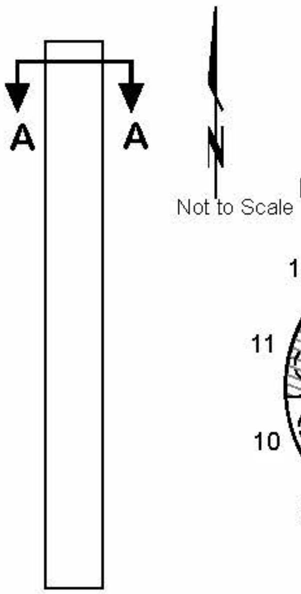
Figure C1

1 Foundation Testing

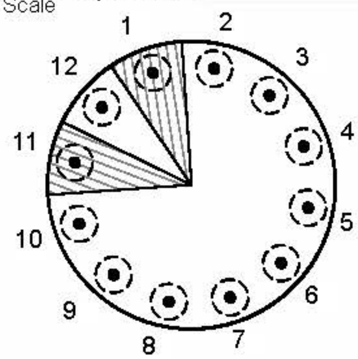
Name: GS-FTB Engr
Phone: 916-227-xxxx
Date:

Testing Performed: X GGL CSL

Section A - A



Elev: 4.6 to 3.6 ft
Depth: 1.2 to 2.2 ft
Diameter: 10 ft
Depth Ref: **Plan Pile Cut-Off Elev.**



Provide the relevant elevations.

Plan Pile Cut-off Elev: 5.75 ft
Plan Const. Joint Elev: NA
Plan Top of Pile Pedestal Elev: NA
Reported Casing Tip Elev: NA
Reported Pile Tip Elev: -133.00 ft

Anomaly Description:
Section A - A: Anomaly was detected in two (2) GGL inspection pipes. May affect up to 17% of shaft cross-section at this location.

2 Geotechnical

(See CT Geotechnical Manual)

Name:
Phone:
Date:

Required Nominal Resistance at top of Shaft (per contract plans):
Compression (kips): 6600 Tension (kips): 0

Required Nominal Resistance at top of Anomaly:
Compression (kips): 6600 Tension (kips): 0

"As-Designed" nominal resistance over entire pile surface from the top to bottom elev. of anomaly/capacity loss within anomaly length (kips):
Compression (kips): 0 / 0 Tension (kips): 0 / 0

Soil and/or Rock Type: Silty Sand

Section is geotechnically: ☑ **Acceptable** ☐ **Unacceptable**

Comments:
The anomalous section is above the pile side resistance zone.

3 Structural

(See MTD 3-7)

Name:
Phone:
Date:

As-Designed Capacity of Shaft at Anomaly
Shear: Moment:

Maximum Demand of Shaft at Anomaly
Shear: Moment:

Note: Section shall also be evaluated for axial capacity at anomaly.

Section is structurally: ☐ **Acceptable** ☐ **Unacceptable**

Comments:

4 Corrosion

Section repair is: ☐ **Required** ☐ **Not Required**

Name:
Phone:
Date:

Comments:

The groundwater elevation must be assessed from the *Geotechnical Report* and *Section 7.6 Cast-in-Drilled-Hole (CIDH) Pile Anomalies* in the most current *California Department of Transportation Corrosion Guidelines*.

5 Oversight Engineer Concurrence

Geotech: Struct: Corr:

6 Construction

Section is: ☐ Acceptable with Administrative Deduction ☐ Unacceptable; Mitigation is Required

Structure Rep:
Phone:
Date:

Comments:

Structure: Struct. No: Support:
Dist-Co-Rte-PM: EA / EFIS: Pile:

Figure C2

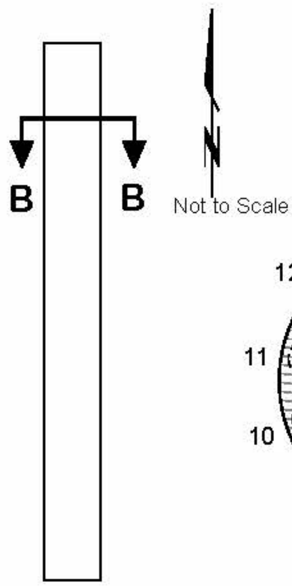
Pile Design Data Form

1 Foundation Testing

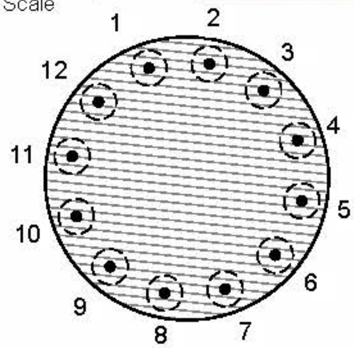
Name: GS-FTB Engr
Phone: 916-227-xxxx
Date:

Testing Performed: X GGL CSL

Section B - B



Elev: -10.8 to -16.0 ft
Depth: 16.6 to 21.8 ft
Diameter: 10 ft
Depth Ref: **Plan Pile Cut-Off Elev.**



Provide the relevant elevations.

Plan Pile Cut-off Elev: 5.75 ft
Plan Const. Joint Elev: NA
Plan Top of Pile Pedestal Elev: NA
Reported Casing Tip Elev: NA
Reported Pile Tip Elev: -133.00 ft

Anomaly Description:
Section B - B: Overlapping anomaly was detected in all twelve (12) GGL inspection pipes. May affect up to 100% of shaft cross-section at this location.

2 Geotechnical
(See CT Geotechnical Manual)

Name:
Phone:
Date:

Required Nominal Resistance at top of Shaft (per contract plans):
Compression (kips): 6600 Tension (kips): 0

Required Nominal Resistance at top of Anomaly:
Compression (kips): 6233 Tension (kips): 0

"As-Designed" nominal resistance over entire pile surface from the top to bottom elev. of anomaly/capacity loss within anomaly length (kips):
Compression (kips): 289 / 289 Tension (kips): 0 / 0

Soil and/or Rock Type: silty sand and fat clay

Section is geotechnically: ☑ **Acceptable** ☐ **Unacceptable**

Comments:
The side resistance below the design side resistance zone, can be used to compensate for the resistance loss within the anomalous section.

3 Structural
(See MTD 3-7)

Name:
Phone:
Date:

As-Designed Capacity of Shaft at Anomaly
Shear: Moment:

Maximum Demand of Shaft at Anomaly
Shear: Moment:

Note: Section shall also be evaluated for axial capacity at anomaly.

Section is structurally: ☐ **Acceptable** ☐ **Unacceptable**

Comments:

4 Corrosion

Comments:

Section repair is: ☐ **Required** ☐ **Not Required**

Name:
Phone:
Date:

The groundwater elevation must be assessed from the *Geotechnical Report* and *Section 7.6 Cast-in-Drilled-Hole (CIDH) Pile Anomalies* in the most current *California Department of Transportation Corrosion Guidelines*.

5 Oversight Engineer Concurrence

Geotech: Struct: Corr:

6 Construction

Section is: ☐ Acceptable with Administrative Deduction ☐ Unacceptable; Mitigation is Required

Comments:

Structure Rep:
Phone:
Date:

Structure: Struct. No: Support:
Dist-Co-Rte-PM: EA / EFIS: Pile:

Example Diagram

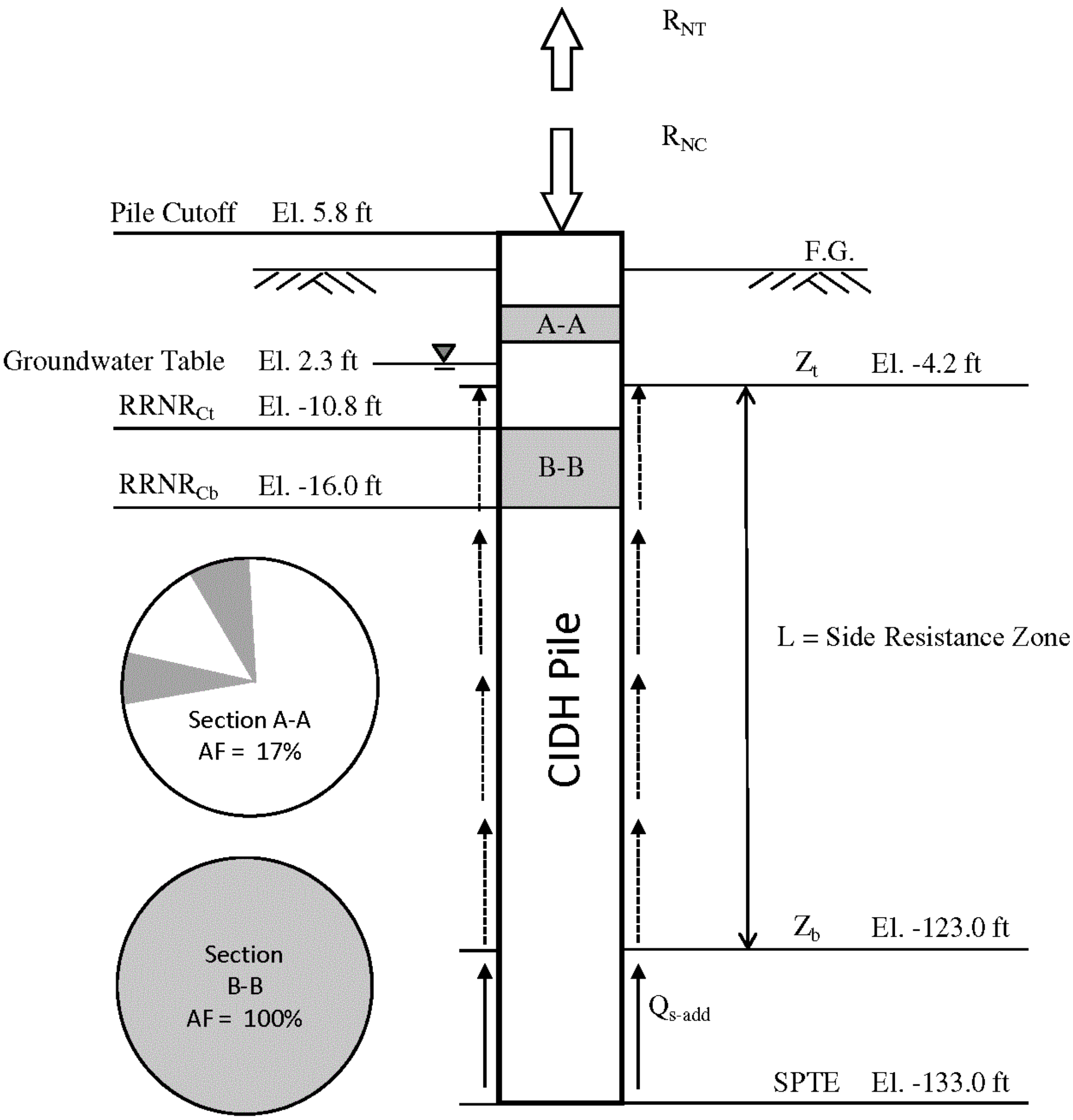
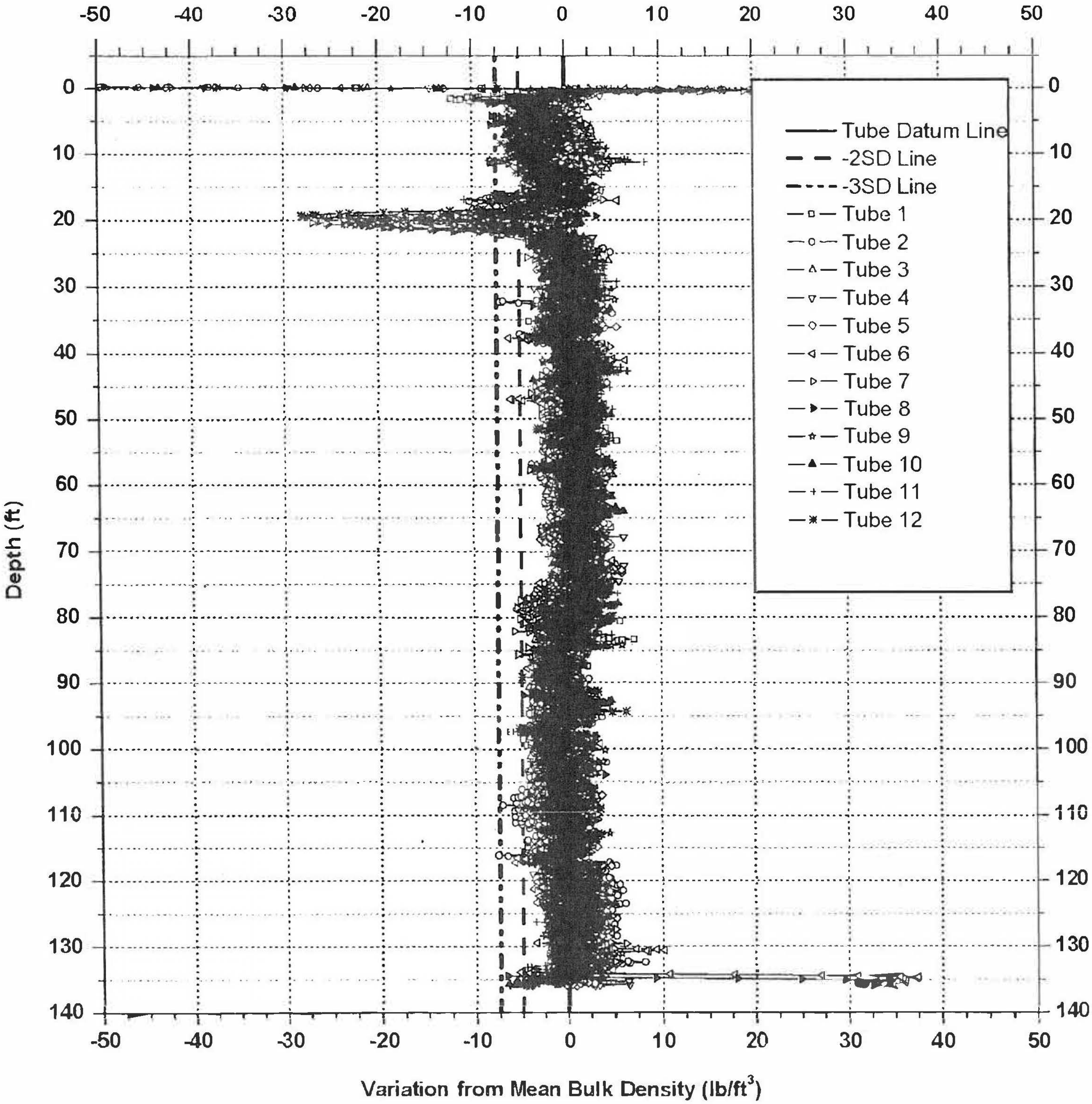


Figure C3



GAMMA-GAMMA LOGGING ACCEPTANCE TEST RESULTS

Deepwater Creek Bridge (Replace)

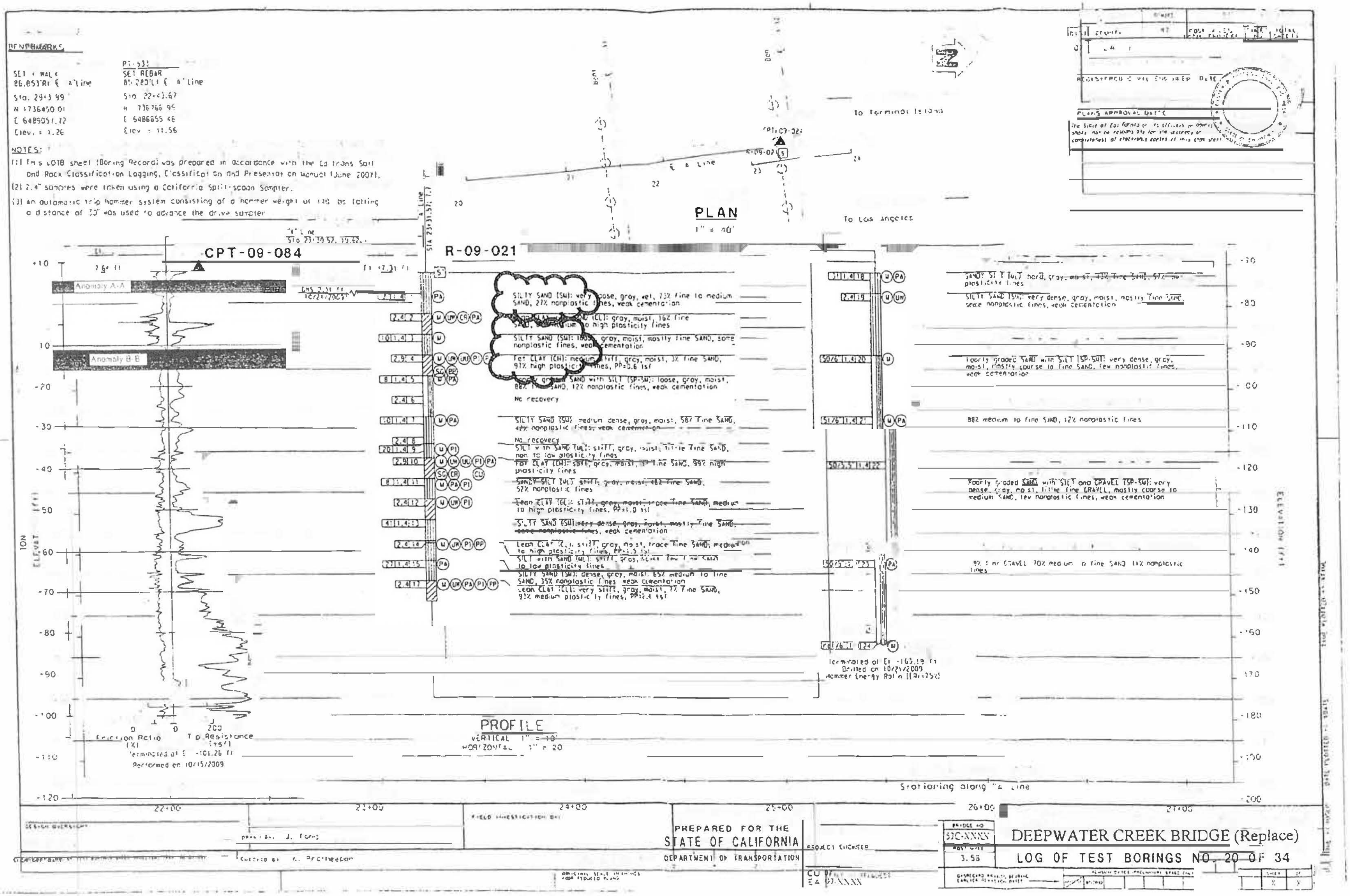
CIDH Pile C at Bent 12

EA 07-XXXX
Bridge Number 53C-XXXX
07-LA-47-
Date Tested: 01/20/2021

10-ft dia. CIDH Pile
Reported Top of Concrete Elev.= +5.75 ft
Reported Tip Elev.= -133.0 ft
Winch-Probe-Source Number: 1273-2575-568

The mean and standard deviation were calculated using density readings for all inspected tubes, excluding portions significantly impacted by reinforcement, anomalies, and water, as appropriate.

Figure C4



PLAN
CPT-09-084
R-09-021
PROFILE
DEEPWATER CREEK BRIDGE (Replace)
LOG OF TEST BORINGS NO. 20 OF 34
PREPARED FOR THE
STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION

Figure C5