DESIGN PROCEDURE AND EXAMPLES

This section presents templates and example tables for communication and exchange of information between the SD and the GD during the foundation design process. MTD 1-35 presents the roles of the SD and the GD during foundation design and refers to this Memo for the specifics presented herein.

At the early stages of design, the SD provides preliminary foundation information to the GD using the Preliminary Foundation Design Data Sheet, shown in Table 3-2, as part of the request for a Preliminary Foundation Report.

Table 3-2. Example of Preliminary Foundation Information

Preliminary Foundation Design Data Sheet		
Support	**Foundation Type(s) Considered**	**Estimate of Maximum Factored Compression Loads (kips)**
Abut 1	Class 140	196 per pile
Bent 2	Class 200 Pile Group 60″ Diameter CIDH Pile Shaft	280 per pile 1850 per column
Bent 3	30″ CIDH Pile Group 60″ Diameter CIDH Pile Shaft	1950 per column
Abut 4	24″ CIDH	280 per pile

Notes:

1. Estimate of maximum factored loads is not required for standard piles, rather provide Factored Nominal Structural Resistance (only at preliminary stage).
2. Maximum factored loads are estimated based on Strength Limit State load combinations.

The request for a Foundation Report is prepared after preliminary structural analysis and includes tables that provide scour data (Table 3-3), general foundation information in the Foundation Design Data Sheet (Table 3-4), and governing loads for different Limit States (Table 3-5).

Table 3-3. Scour Data Table

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

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Table 3-4. General Foundation Information to be sent from the SD to the GD

Foundation Design Data Sheet							
Support No.	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″	

* Based on CALTRANS' current practice, the total permissible settlement is one inch for multi-span structures with continuous spans or multi-column bents, one inch for single span structures with diaphragm abutments, and two inches for single span structures with seat abutments. Different permissible settlement under service loads may be allowed if a structural analysis verifies that required level of serviceability is met.

Table 3-5. Design Loads to be sent from the SD to the GD

Foundation Factored Design Loads										
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 Loads 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										
Bent 2										
Bent 3										
Abut 4										

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The GD provides complete foundation recommendations in the Foundation Report in accordance with the current Foundation Report preparation standard. 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 facilitates completion and usage of the pile data table:

1. The modified Gates formula (Standard Specifications, 49-2.01) provides an estimate of nominal driving resistance of the piles. The modified Gates formula is used to determine pile acceptance of driven pile unless otherwise noted by GS.

2. The required nominal resistance must be shown for all piles, regardless of pile type or acceptance criteria. The nominal resistance shall be rounded up to the nearest 10 Kips.

3. 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. Pier columns, column shafts, and pile extensions which have no footings, require a cut-off elevation in the Pile Data Table.

4. The design tip elevations for compression, tension, lateral, and settlement shall be 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.

5. The specified tip elevation is the controlling (deepest) value of the design tip elevations.

6. The Standard Specifications allow the contractor to revise specified tip elevations as long as the required nominal resistance is verified through a static load test, and other design criteria such as tension, lateral and settlement are met. The nominal resistance is also needed for acceptance by Wave Equation Analysis. The specified tip elevation shall not be raised above the design tip elevations for tension, lateral, and in some cases for tolerable settlement without consent of GS. The static load test used to verify nominal resistance cannot duplicate these conditions.

7. The values of geotechnical resistance factors (φ) used in Attachment 1 examples is explanatory. The GD needs to refer to AASHTO LRFD BDS and California Amendments for selection of the applicable resistance factor(s).

The information to be provided to 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 GD provides design and specified pile tip elevations as well as “Factored Nominal Resistance” of the piles and corresponding “Resistance Factors”. The SD will calculate the “Nominal Resistance” of the piles and will finalize the pile data table to be shown in the plans.

- Example #1 – Standard Plan Piles, CIDH Piles, and CISS Piles
- Example #2 – Steel HP Piles and CIDH Piles w/ Permanent Steel Casing
- Example #3 – Large CIDH Piles w/ Driven Steel Shells

Example 1) Standard Plan Piles, CIDH Piles, and CISS Piles

A three span over-crossing with single column bents, and seat abutments (constructed in competent soil) uses Standard Plan piles. 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 information required for each case.)

Table 3-6 shows an example of information provided by the GD for abutments and bents. However, design tip elevations for lateral loads are commonly determined by the SD and will be added in Table 3-7. Resistance Factors (φ) for Strength and Extreme Event load cases are also given in Table 3-6. Typical footnotes shown under the tables are project specific and will be included in the Foundation Report (FR) and Pile Data Table for clarification.

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Table 3-6. Foundation Recommendations

Foundations Design Recommendations												
Support Location	Pile Type	Cut-off Elevation (ft)	Service-I Limit State Load per Support (kips)		Total Permissible Support Settlement (inches)	Required Factored Nominal Resistance (kips)				Design Tip Elevations (ft)	Specified Tip Elevation (ft)	Required Nominal Driving Resistance (kips)
						Strength/Construction		Extreme Event				
			Total	Permanent		Comp. ($\varphi = 0.7$)	Tension ($\varphi = 0.7$)	Comp. ($\varphi = 1.0$)	Tension ($\varphi = 1.0$)			
Abut. 1	Class 140	72	1340	1040	1	196	0	N/A	N/A	30(a-I) 31(c) 34(d)	30	280
Bent 2	CISS 24x0.5	59	1750	1380	1	268	126	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	**285**	121	**380**	186	6(a-I) 12(b-I) 9(a-II) 12(b-II) 3(c) 15(d)	3	N/A
Abut. 4	Class 140	78	1260	870	1	182	0	N/A	N/A	32(a-I) 31(c) 34(d)	31	280

Notes:

1) 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.
2) The specified tip elevation shall not be raised above the design tip elevations for tension, lateral, and tolerable settlement.
3) The nominal driving resistance required is equal to the nominal resistance needed to support the factored load 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.
4) Design tip elevation for Lateral Load is typically provided by the SD.

Table 3-7 shows the foundation information that the SD puts on the contract plans. When Strength Limit State load combinations control factored load, resistance factors for both compression and tension will be specified by the GD, so that the nominal resistance equals the factored load divided by the resistance factor. When Extreme Event Limit states (such as seismic) control the factored load, resistance factors for both compression and tension will be $\Phi = 1.0$, so that the nominal resistance equals the pile's factored load demand. The factored loads under tension and compression for both Strength and Extreme Event Limit States shall be considered when calculating Nominal Resistance of piles. As an example, the Compression Nominal Resistance for Bent 3 piles will be the greater of 285/0.7 and 380/1.0, that is 407kips, rounded up to 410 kips, as shown in Table 3-7. Design tip elevations for compression and tension under Strength and Extreme Event Limit States are compared and only the lower elevations for each load will be shown as Specified Tip Elevation in the Pile Data Table.

Table 3-7. Pile Data Table

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	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	260	0	32(a) 31(c) 34(d)	31	280

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 tolerable settlement.
3) Unsuitable soil layers (very soft, liquefiable, scourable, etc.) that do not contribute to the nominal resistance exist at Abutment 4 and Bent 2 extending to elevations 65 ft and 48 ft, respectively.

Example 2) CIDH Piles with Permanent Casing

The following example shows Foundation Recommendations and the Pile Data Table for a typical multi-column under-crossing bent (pinned footings). CIDH piles with permanent steel casing will be used at the bent. The purpose of permanent steel casing is to facilitate construction and does not contribute to the geotechnical resistance. In addition to information given in Table 3-6, the GD will also provide the Steel Casing Specified Tip Elevation as shown in Table 3-8. The Steel Casing Specified Tip Elevation will be also shown in the Pile Data Table (Table 3-9). Tables 3-8 and 3-9 will be provided by the GD.

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Table 3-8. Foundation Recommendations

Foundations Design Recommendations												
Support Location	Pile Type	Cut-off Elevation (ft)	Service-I Limit State Load per Support(kips)		Total Permissible Support Settlement (inches)	Required Factored Nominal Resistance (kips)				Design Tip Elevations (ft)	Specified Tip Elevation (ft)	Steel Casing Specified Tip Elevation (ft)
						Strength/Construction		Extreme Event				
			Total	Permanent		Comp. ($\varphi = 0.7$)	Tension ($\varphi = 0.7$)	Comp. ($\varphi = 1.0$)	Tension ($\varphi = 1.0$)			
Bent 2	48″ CIDH piles with permanent steel casing	85	2670	2150	1	321	76	389	118	25 (a-I) 29(b-I) 30(a-II) 27(b-II) 24 (c) 26(d)	24	40

Notes:

1) DesignTip 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.
2) The CIDH Specified Tip Elevation shall not be raised.
3) Design Tip Elevation for Lateral Load is typically provided by the SD.

Table 3-9. Pile Data Table

Pile Data Table						
Location	Pile Type	Nominal Resistance (kips)		Steel Casing Specified Tip Elevation (ft)	Design Tip Elevation (ft)	Specified Tip Elevation (ft)
		Compression	Tension			
Bent 2	48″ CIDH piles with permanent steel casing	460	120	40	25 (a) 27(b) 24(c) 26(d)	24

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 Driven Steel Shell

The following example is the seismic retrofit of a major river crossing bridge where large diameter CIDH piles with permanent driven steel shells are recommended. The shell is required to facilitate construction and to develop a portion of the required geotechnical nominal resistance. The shell is to be installed by impact driving and "Wave Analysis" will be used for pile acceptance. Shown in Table 3-10 are the foundation design recommendations provided by the GD. Table 3-11 shows pile data table to be shown on the plans.

Table 3-10. Foundation Recommendations for Bents

Foundations Design Recommendations										
Support Location	Pile Type	Cut-off Elevation (ft)	Required Factored Nominal Resistance for Extreme Event Limit State (kips)				Driven Steel Shell Specified Tip Elevation (ft)	CIDH Design Tip Elevations (ft)	CIDH Specified Tip Elevation (ft)	Steel Shell Required Nominal Driving Resistance (kips)
			CIDH Pile		Driven Steel Shell					
			Comp. (φ = 1.0)	Tension (φ = 1.0)	Comp. (φ = 1.0)	Tension (φ = 1.0)				
Bent 2	60″ CIDH piles with 72x0.75″ Driven Steel Shell	116	1112	472	586	249	-42	-51 (a-II) -46 (b-II) -48 (d)	-51	700

Notes:
1) 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.
2) The CIDH Specified Tip Elevation shall not be raised.
3) The nominal driving resistance required 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.),which do not contribute to the design resistance. Unsuitable soil layers at Bent 2 extend to elevation of -11 ft.
4) Design Tip Elevation for Lateral Load is typically provided by the SD.

Attachment 1

Table 3-11. Pile Data Table

Pile Data Table									
Location	Pile Type	Nominal Resistance (kips)		Nominal Resistance (Driven Steel Shell) (kips)		Driven Steel Shell Specified Tip Elevation (ft)	CIDH Design Tip Elevations (ft)	CIDH Specified Tip Elevation (ft)	Steel Shell Nominal Driving Resistance (kips)
		Compression	Tension	Compression	Tension				
Bent 2	60″CIDH piles with 72x0.75″ Driven Steel Shell	1120	480	590	250	-42	-51 (a) -46 (b) -48 (d)	-51	700

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.
3) Unsuitable soil layers (very soft, liquefiable, scourable) that do not contribute to the design nominal resistance exist at Bent 2 extending to elevation of -11 ft.