3-7 DESIGN DATA DOCUMENTATION AND EVALUATION OF ANOMALOUS CONCRETE SHAFTS

Introduction

Cast in Drilled Hole (CIDH) Shafts (also known as CIDH Piles), and Cast in Steel Shell (CISS) concrete piles are commonly used when large vertical or lateral resistance is required. When ground water is anticipated drilled shafts must be at least two feet in diameter and must be inspected by Gamma-Gamma Logging (GGL), and may require inspection by Cross-Hole Sonic Logging (CSL). Memo to Designers 3-1 (MTD 3-1) provides guidelines for the required number of inspection tubes and the proper placement of the tubes to improve constructability. MTD 3-1 requirements for placement of inspection tubes may require the designer to use bundled bars or increase the size of the shaft. Communications with Structure Construction and Geotechnical Services during design and CIDH pile pre-construction meeting will improve shaft constructability and may prevent costly delays and anomaly mitigations.

The Foundation Testing Branch (FTB) of Geotechnical Services performs GGL and CSL on CIDH piles together with other Quality Assurance (QA) procedures. The main objective of GGL is to investigate uniformity of concrete density, where significant reduction in density identifies anomalies. CSL is used to assess integrity of concrete and detect presence of voids or anomalies. GGL is the primary test in Caltrans, and CSL is used as a complement to provide more detailed information about location and size of the anomaly. When defects are detected Structure Design (SD), Geotechnical Services (GS), and Corrosion Technology Branch of Materials Engineering and Testing Services (METS) are contacted. Considering short timeframe requirements specified in the Construction Standard Specifications, the information required for structural evaluation of a potential anomaly should be prepared during the design phase. This memo provides guidelines for documentation of the design data and location to be retained, the structural evaluation process of rejected shafts, and an example to clarify the process.

CIDH Shaft Design Data Documentation

If slurry displacement method is used to construct CIDH shafts, the FTB will perform non-destructive testing to evaluate homogeneity of the concrete shaft. When the testing detects an anomaly the shaft is rejected. Structure Construction collects design information from GS, SD and Corrosion Technology Branch to evaluate the rejected shaft. Gathering this information is required to determine if the shaft is “adequate” or “inadequate” with the anomaly in place.

Structural evaluation must be completed within the timeframe specified in the contract's documents, or the State may incur costs associated with delays. To prevent such delays, the Project Engineer or DES Liaison/Oversight Engineer shall compile the necessary design information for each CIDH pile during the Plans, Specifications & Estimate (PS&E) phase of the project. The information shall be checked and retained in the project files and must be easily accessible during the construction phase. Furthermore, the SD Branch Chief or Consultant Structure Lead (or Structure Project Manager) will verify that information is complete, and will complete and sign the Shaft Design Information Form, as shown in Attachment 1 (Figure 1 for Caltrans Designed Projects; Figure 2 for Consultant Designed Projects, whichever is applicable). The form is forwarded to Structure Construction, Resident Engineer's (RE) Pending File as a part of Structures Plans, Specifications, and Estimates (SPS&E) package.

Design information to be retained and required for evaluation generally include "Factored Shear Force and Bending Moment Diagrams" along the pile length, shear and moment capacities assuming no anomaly is present, and electronic input files (such as X-Section files) for capacity calculations. The designer will need to envelope the maximum shear, moment, and axial demands that may occur during the life of the structure for different limit states, construction stages, and also combinations of scour and liquefaction (if applicable). This information will be saved in the design branch for the construction support phase as stated above. Shear and flexural capacities of the defective shaft are also required for structural evaluation. However, this portion cannot be completed until the location and size of the anomaly (if any) is known.

Pile Design Data Form

After the contractor has constructed a CIDH-concrete pile using the slurry displacement method, the FTB will perform California Test Method (CT) 233 – "Method for Ascertaining the Homogeneity of Concrete in CIDH Piles Using the Gamma-Gamma Test Method." If acceptance testing performed by the engineer determines that a shaft does not meet the requirements of the specifications of CTM 233, Part 5C, then the shaft will be rejected.

After the shaft has been rejected, the State has a limited amount of time to make a determination on which of the following options is available to the contractor for dealing with the rejected shaft:

1) The shaft must be supplemented or replaced.

2) The shaft must be repaired.

3) The shaft is adequate with the anomaly left in place.

Pile Design Data Form (PDDF) is used to collect information from various units of the Division of Engineering Services (DES) to determine if anomaly needs to be repaired. The FTB will complete Part 1 of the PDDF (see Attachment No. 2 of Bridge Construction Memo 130-10). This information will identify the severity and the location of the anomaly within the shaft and will be used by GS to complete Part 2, SD to complete Part 3, and the Corrosion Technology Branch to complete Part 4 of the form.

The following information is required for structural evaluation and to complete Part 3 of the form (Structural):

a) As designed shear and moment capacities at the location of the anomaly. These values are calculated from design phase information, assuming that the shaft would not contain any defects.

b) The shear and moment demands at the location of the anomaly. This information (demands and as-designed capacities) should be readily available to the Structure Design personnel conducting construction support, since it may be time consuming to reproduce this data.

c) The reduced shear and moment capacities of the defective shaft at the location(s) of the anomaly. This step will be explained in the Example of Evaluation Process illustrated in this Memo.

d) Determination if the shaft is structurally adequate with the anomaly left in place. Structure Design will make this determination using the information above and engineering judgment considering uncertainty in the nature of the anomaly. It is important to point out that the evaluation process must be completed within the time frame specified in the contract.

If the shaft is determined to be adequate with the anomaly in place, then the contractor may choose to repair the shaft and receive full payment or leave the anomaly and incur an administrative deduction specified in the contract. If the shaft is determined to be inadequate, then the anomaly mitigation process will start. BCM 130-12 provides detailed information regarding the mitigation process and methodology.

Structural Evaluation of Anomalous Shafts

In general, structural evaluation of the shaft at the anomaly location includes comparing reduced bending, shear and axial capacities to corresponding Strength and Extreme Event (seismic) demands. However, for shaft groups in competent soil, limited bending is developed in the shaft. Therefore evaluation will be limited to axial and shear capacity checks.

The evaluation should be performed with and without scour and liquefaction effects, if applicable. Therefore, up to four different combinations must be considered. In the design phase, the location of the potential anomaly is unknown; therefore, demands for all applicable cases must be compiled and recorded as moment and shear diagrams or tables for the entire length of the shaft. Factored axial load, which is equivalent to factored nominal compression resistance of the shaft, can be easily extracted from the Pile Data Table.

GGL results identify the tube(s) with unacceptable low concrete density reading(s); therefore, designer may conservatively eliminate the tributary slice(s) corresponding to tube(s) with low reading(s). CSL results may provide more detailed information about the size of the anomaly and will improve strength evaluations. Following is a summary of the typical structural evaluation process:

Flexural Capacity Calculations

Use sectional analysis software (such as X-Section Program) to calculate the flexural capacity of the anomalous shaft (M_{ne} or M_p, that is expected nominal moment or plastic moment of the section, respectively). Modeling assumptions will depend on the type of the testing as summarized below.

GGL results: When GGL detects unacceptable low readings in a single tube or multiple adjacent tubes, the corresponding tributary slice(s) will be assumed to be a void (without concrete and rebar), and flexural capacity will be calculated in a direction that causes compression in the lost slice(s) of the section. When multiple non-adjacent tubes show unacceptable low readings, flexural capacity must be assessed in different directions (30 degree intervals), and the minimum value will be used.

CSL results: The approximate size and location of the anomaly detected by CSL will be assumed to be a void, and the flexural capacity of the cross section will be calculated in different directions (30 degree intervals) and the lowest capacity will be used.

Evaluation for Bending and Shear

Considering approximations in assessing the size of the anomaly, acceptance criteria for bending and shear under the Extreme Event (seismic) Limit State is as follows:

Type-II Shafts

GGL results: The moment and shear checks are summarized as:

$$M_d \leq M_{ne}{}^R \text{ and } V_d \leq \varphi V_n{}^R$$

CSL results: The moment and shear checks are summarized as:

$$M_d \leq 0.8\, M_{ne}{}^R \text{ and } V_d \leq \varphi V_n{}^R$$

where M_d and V_d are seismic moment and shear demands at the location of the anomaly when applying over-strength moment (M_o) at the column base. $M_{ne}{}^R$ is the expected nominal moment of the reduced cross section of the shaft at the location of the anomaly, and $\varphi V_n{}^R$ is the factored nominal shear resistance of the reduced cross section of the shaft as defined in Caltrans' Seismic Design Criteria (SDC 3.6.7). In calculating shear resistance of concrete, the cross section of the shaft is reduced in proportion to the size of the anomaly ($V_c{}^R$). Since the detected anomaly

indicates concrete with lower density rather than a void, the shear reinforcement is assumed functional when calculating V_s. This simplified approach for calculation of V_n^R is limited to shallow anomalies, where thickness of the anomaly (measured along the shaft) is less than half of the diameter of the shaft. For deeper anomalies, special analysis is required to determine V_s contribution to shear resistance of the shaft. The shear resistance of permanent steel casing or shell can be included in shear capacity calculations, irrespective of the thickness of the anomaly.

Type-I Shafts and CIDH Pile Groups in Liquefied Soil (if plastic hinges form in the shafts)

GGL results: Seismic moment demand (M_d) at the location of the anomaly should be less than $1.25M_p^R$ for multi-column bents and $1.15M_p^R$ for single column bents. M_p^R is the plastic moment of the reduced shaft cross section at the location of the anomaly. Seismic shear demand at the location of the anomaly (V_d) shall be less than the nominal shear resistance of the pile (φV_n^R), as defined in SDC 3.6.1. In calculation of shear resistance of concrete (V_n^R), the cross section of the shaft is reduced in proportion to the size of the anomaly. However, contribution of shear reinforcement (V_s) is not reduced. This simplified approach for calculation of V_n^R is limited to shallow anomalies, where depth of the anomaly is less than half of the diameter of the shaft. For deeper anomalies, more refined analysis is recommended.

CSL results: Seismic moment demand (M_d) at the location of the anomaly should be less than M_p^R. The shear check will be the same as the GGL case.

Evaluation for Compression

For both GGL and CSL testing, factored nominal compression resistance of the shaft at the anomaly location is checked based on the reduced cross sectional area of the shaft along with Load and Resistance Factored Design (LRFD) Specifications and California Amendments, as follows:

$$P_u \leq \phi P_n^R$$

Where $\phi = 0.75$, $P_n = 0.85[0.85f'_c (A_g - A_{st}) + f_y A_{st}]$, and P_n^R is calculated by reducing P_n in proportion to the number of tubes with unacceptable low readings

Refer to LRFD BDS (5.7.4.4) for definition of terms. Factored resistance must be checked against factored loads for Strength Limit State load combinations.

Attachment 2 provides an example of the evaluation process for a Type-II shaft with anomalies detected by both GGL and CSL. Attachment 3 is the PDDF of the example with design information added after structural review.

References:

Bridge Memo to Designers 3-1: Deep Foundations, Office of Structure Design, Division of Engineering Services, California Department of Transportation, Sacramento, CA, July 2008.

Bridge Construction Memos 130-10.0 and 130-12.0, Bridge Construction Records and Procedures Manual, Offices of Structure Construction, Division of Engineering Services, California Department of Transportation, Sacramento, CA, 2007.

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AASHTO LRFD Bridge Design Specifications, 4th Edition with 2008 Interims, AASHTO, Washington, D.C., 2007.

California Amendments to *AASHTO LRFD Bridge Design Specifications*, California Department of Transportation, Sacramento, CA, 2008.

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