**SAMPLE SPECIFICATION for CROSSHOLE SONIC LOGGING (CSL)**

May 1, 2024

*The user of this sample specification should recognize that each project has unique requirements. Crosshole sonic logging can be applied to drilled shafts, tangent and secant walls, barrettes, and slurry wall panels. Therefore, this sample specification will refer to these foundation types hereafter as deep foundation elements. The project foundation type and its installation procedures, geometry and reinforcement details should be considered in modifying this sample specification to address and satisfy project specific requirements. This sample specification includes commentary throughout to facilitate final specification development by the end user. Contractual items are limited since each owner, agency, or project has its own requirements and procedures.*

1. **DESCRIPTION**

Crosshole Sonic Logging (CSL) assesses the structural integrity of the concrete between access tubes in a deep foundation element as well as the extent and location of defects, if encountered. The CSL procedure sends ultrasonic pulses through the concrete from one probe to another probe or probes located in parallel tubes. Both the time between pulse generation and signal reception (“First Arrival Time” or “FAT”), and the strength of the received signal give a relative measure of the quality of concrete between the probes. Dividing the distance between transmitter and receiver by the FAT value yields the approximate concrete wave speed which is also a relative indicator of concrete quality. For equidistant tubes, uniform concrete between the test tubes yields consistent arrival times with reasonable pulse wave speed and good signal strengths. Non-uniformities such as contaminated or soft concrete, honeycombing, voids, and inclusions exhibit delayed arrival times with reduced signal strength. CSL procedures are standardized by ASTM D-6760, Standard Test Method for Integrity Testing of Concrete Deep Foundations by Ultrasonic Crosshole Testing.

1. **SUBMITTALS**

**2.1 Qualifications of CSL Consultant.** The CSL Consultant shall be an independent testing agency having at least one (1) year of experience in CSL testing and having completed five (5) projects of comparable complexity. The CSL Consultant responsible for performing and interpreting the CSL results shall be a licensed professional engineer in the project location. The CSL Consultant qualifications and the specifications of their proposed CSL testing equipment shall be submitted to the Engineer for approval prior to beginning \_\_\_\_\_\_\_\_ (*drilled shaft, tangent or secant wall, barrette, or slurry wall)* installation.

**3.0 MATERIALS AND EQUIPMENT**

**3.1 Access Tubes.** Each reinforced deep foundation element shall be equipped with access tubes to permit possible CSL testing. The contractor shall furnish and install nominal 1.5- or 2.0-inch inside diameter, standard weight, schedule 40 steel tubes, or schedule 40 or 80 PVC pipes in each foundation element. The number of tubes to be installed shall be based upon the foundation type, dimensions, and construction sequencing. Refer to Section 3.2 for tube quantity and spacing requirements.

***Commentary:*** *Steel access tubes are preferred and highly recommended. If long PVC tubes are used, Schedule 80 PVC is recommended. Experience suggests PVC tubes may be subject to “debonding” of the PVC with concrete in the upper part of the foundation, particularly if the foundation element is cast under wet/slurry conditions. In those cases, testing of elements with PVC tubes should be done as soon as possible after casting to minimize debonding effects since debonding may prevent obtaining interpretable results.*

*The actual cost of the access tubes is low compared to the cost of the foundation. Installing tubes in all foundation elements is highly recommended so that any foundation can later be tested if some difficulty is encountered during construction. Failing to install access tubes during installation would either prevent CSL testing or add significant costs for drilling core holes.*

Round tubes with a regular internal diameter free of defects and obstructions, including any tube joints, shall be used to permit the free, unobstructed passage of the CSL probes. Tubes shall be watertight and free from corrosion with clean external faces to ensure a good bond between the concrete and the tubes. Tubes may be extended with mechanical couplings. Duct tape or other wrapping material to seal the joints and butt welding of joints are prohibited. When couplings are used, record their location. Tubes shall be installed by the Contractor in a manner such that the CSL probes pass through the entire length of the tube without binding. Ensure that the access tubes are plumb and confirm that unobstructed passage of the probes is achievable before the CSL Consultant arrives. The tubes shall have a watertight shoe on the bottom and a removable cap on the top. Tubes shall be secured to the interior of the reinforcement cage at regular intervals not exceeding three feet.

***Commentary:*** *When access tubes do not allow the probe to pass through the entire length of the tube due to poor workmanship, replacement access holes may be required and can be constructed by core drilling.*

*For spliced cages, alignment and field splicing of the access tubes must be carefully planned and implemented to reduce injury risk to the field crew from tube or cage slippage.*

After placement of the reinforcement cage in the foundation element, the access tubes shall be filled with clean fresh water as soon as possible but no later than two hours after concrete placement. Immediately after filling, the tube tops shall be capped to prevent debris from entering the access tubes. When removing the caps from the tubes for testing, do not apply excessive torque, hammering or other stresses which could break the bond between the tube and concrete.

***Commentary:*** *To reduce the risk of debonding due to differential temperatures, best practice is to fill the tubes with water* ***prior*** *to concrete placement. If construction conditions prevent tube filling prior to concrete placement, the tubes must be filled with water immediately following pour completion. This is particularly important for PVC access tubes.*

**3.2 Required Tube Quantities and Spacing.** Depending upon the deep foundation element being constructed, the element may have a circular, rectangular, or other multi-faced shape. In circular reinforced elements, install one access tube for every 10 to 14 inches of foundation diameter, with a minimum of four access tubes. Access tubes shall be placed inside the spiral or hoop reinforcement, three inches clear of the vertical reinforcement, at a uniform spacing measured along the circle passing through the centers of the access tubes. In rectangular or other multi-faced elements, access tubes shall be placed at a maximum spacing not exceeding a distance of \_\_ *(typically five)* feet between tube centers. If these minimums cannot be met due to close spacing of the vertical reinforcement, then bundle the access tubes with the vertical reinforcement.

***Commentary:*** *Drilled shafts and tangent walls typically have circular reinforcing cages. Secant walls frequently have unreinforced circular primary elements subsequently intersected by reinforced circular secondary elements. Barrettes may be constructed as reinforced rectangular,* T, L, X *or* H *shapes. Slurry wall panels are typically reinforced and rectangular. Access tube quantities and tube spacing therefore varies depending upon the foundation element type and reinforcement.*

Tubes shall be installed uniformly and equidistantly around the element circumference or perimeter such that each tube is spaced parallel for the full length and at the maximum distance possible from each adjacent tube. Tubes shall be spaced as far as possible from the main axial reinforcing steel. Tubes shall be extended to within six inches of the bottom of the element, to at least three feet above the top of the concrete, and to at least two feet but not more than five feet above the ground surface. Tubes shall not be damaged during installation of the reinforcement cage.

***Commentary:*** *Many specifications prohibit access tubes resting on the bottom of the foundation excavation. The access tube bottom elevations are very important to result interpretation when results indicate anomalies at the foundation base.*

**3.3 Access Holes.** In deep foundation elements cast without access tubes, access holes can be created by rotary or core drilling techniques to allow probe access and CSL testing to be performed. The hole diameter should be compatible with the probe diameter to be used for CSL testing. Access holes should be located approximately six inches inside the reinforcement cage. If core drilling is used, core holes should be logged including descriptions of any inclusions or voids. Hole alignment can be checked by independent means if required. Core holes must be filled with clean water prior to CSL testing.

*Commentary: Depending on the probe O.D. and core hole I.D., spacers may be required on the CSL probes to center the probes within the core holes. Core hole deviation can be checked by an inclinometer or ShapeArray.*

**3.4 CSL Equipment.** Provide a CHAMP-Q Cross Hole Sonic Logging System manufactured by Pile Dynamics, Inc., 30725 Aurora Road, Cleveland, OH 44139, USA; [www.pile.com/pdi](http://www.pile.com/pdi); email: info@pile.com; phone: +1 216-831-6131 or equivalent CSL equipment. The equipment shall have the following minimum requirements:

1. A computer based CSL data acquisition system for display of signals during data acquisition, with a minimum 12 bit A/D converter with a sampling frequency of at least 500,000 Hz, and recording of all pulse signals for full analysis and individual signal review.

Commentary: *Converting signals with low noise using high A/D resolution and sampling rates is important to obtain quality data and allow proper data interpretation.*

1. Ultrasonic transmitter, receiver, or transceiver probes capable of producing records at a minimum frequency of 40,000 Hz with good signal amplitude and energy through good quality concrete. The probes shall be less than 1.1 inches in diameter and shall freely descend through the full depth of properly installed access tubes.
2. Depth sensors to independently determine probe depths; one depth sensor for each transmitter, receiver, or transceiver probe.
3. Triggering of the recording system time base with the transmitted ultrasonic pulse.
4. Measuring distance capability between probes of up to 10 ft.

**4.0 TESTING**

**4.1 Foundation Information.** Prior to CSL testing, the Contractor / foundation subcontractor shall provide the following information to the CSL consultant for each foundation element to be tested:

* as-constructed foundation lengths,
* as-constructed concrete top and bottom elevations,
* tube lengths and positions,
* tube splice locations,
* construction dates,
* construction records including casing, auger, and excavation details, etc,
* concrete pour log.

**4.2 Contractor Assistance.** The Contractor shall provide cooperative assistance, suitable access to the site and the foundation elements to be tested, and labor as required to assist the CSL Consultant in performing the required tests.

**4.3 Test Quantities.** CSL testing shall be performed on \_\_\_ *(all, a number, or a percentage)* of the deep foundationelements. The elements to be tested shall be chosen after installation by the Engineer.If significant irregularities are identified, the number of elements tested may be increased by the Engineer.

***Commentary:*** *If only a percentage of elements are tested, elements selected for testing should be based on construction records. Additional foundation elements should be selected at random by the Engineer. When one foundation consists of multiple elements, the number of elements tested should increase as the number of elements decreases due to reduced redundancy in the foundation.* *For sensitive or critical structures, or for those with minimal foundation redundancy, every element should be tested.*

**4.4 Date of Testing.** The deep foundation element shall be tested no sooner than three calendar days after placement of all concrete in any element, but within 10 days after placement and prior to load testing of test elements, or within 45 days after placement on production elements.

***Commentary:*** *CSL testing can be performed after the concrete has obtained sufficient strength (e.g. 66% of design f’c). ASTM D6760 stipulates tests be performed no sooner than three to seven days after casting with wait times closer to seven days for larger elements. Because the concrete strength and quality generally increases as the concrete cures, longer wait times are usually desirable, particularly if minimum pulse wave speeds are specified or to reduce result variability between foundation elements or even as a function of depth within a single foundation element.*

*If PVC tubes are used for wet cast elements (e.g. cast under slurry), long wait times increase the potential for tube debonding which is detrimental to a successful test. CSL testing inside PVC tubes is therefore recommended as soon as practical in the acceptable test window.*

**4.5 CSL Procedure**. Access tubes shall be clearly labeled by the CSL Consultant prior to testing. Probes shall be lowered from the top, effectively measuring the access tube lengths. Remove all slack from the probe cables prior to pulling to provide accurate depth measurements in the CSL records. Testing shall be performed with the transmitter and receiver probes in the same horizontal plane in parallel tubes. Probes shall be pulled simultaneously from the bottom to the top of the foundation element with CSL records taken at intervals of two inches or less. Testing shall be performed between all adjacent perimeter access tube pairs and across at least all major diagonals within the foundation element. If anomalous zones are indicated elements with more than four access tubes, additional CSL testing of other diagonal tube pairs shall be performed to delineate the extent of the questionable zone.

Anomalies are indicated by increases in first arrival times (FAT) and reduced amplitude/energy signals in accordance with the criteria presented in Section 5.2. Anomalous zones should be further evaluated by performing angled tests (source and receiver vertically offset in the tubes) surrounding the effected tubes. Anomalous data shall be reported to the Engineer as soon as possible. Further analysis of the test data with tomography techniques may be required.

If CSL results indicate potential debonding between the access tube and the concrete, an alternative test method shall be required to evaluate the concrete integrity in the debonded region.

***Commentary:*** *Debonding can sometimes be corrected by flooding the top of the foundation element with water and then re-testing. Additional tests or analysis options may also be considered to further evaluate foundation elements with anomalous zones. These options include tomography analysis, gamma-gamma nuclear density logging, sonic echo or impact response tests, high strain dynamic pile testing, static load testing, or concrete coring. When cores are performed, an accurate core log should be maintained including depth and core recovery. Recovered cores and coring logs shall be properly identified and given to the Engineer.*

**5.0 ANALYSIS AND REPORTING**

**5.1 CSL Results.** Results of the CSL tests shall be presented in a written report within five working days of completion of testing. The report shall include a presentation of CSL logs for all tested tube pairs and their identification and orientation relative to the structure. For every tube pair, the report shall include:

1. Presentation of the traditional nested signal peak (e.g. “waterfall”) diagram as a function of time plotted versus depth.
2. Computed pulse first arrival time (FAT) or pulse wave speed versus depth.
3. Computed relative pulse energy or amplitude versus depth.

The report shall also include an interpretation of the CSL test results in accordance with the recommendations published by the Deep Foundations Institute (2019) provided in Section 5.2.

**5.2 CSL Interpretation Criteria.** The interpretation criteria for concrete integrity evaluation from the CSL test results shall follow the recommendations published by Deep Foundations Institute (2019). CSL results are defined by the First Arrival Time (FAT) increase and relative energy reduction into Class A, Class B, or Class C. Depending on the result classification, additional interpretation steps may be required. The DFI rating criteria is summarized below.



***Class A.*** CSL results are classified as *Acceptable CSL Results*. No additional assessment is required.

***Class B.*** CSL results are classified as *Conditionally Acceptable CSL Results*. The number of affected profiles with Class B occurrences and their location within the foundation element shall be reported for further evaluation. This may include a desktop study of both the affected and unaffected portions of the foundation element cross-section, concrete strengths, and additional foundation installation information to determine if any additional evaluation and analysis is warranted. Re-testing of the foundation element after additional curing time, after flooding to address de-bonding, to collect data from all profiles, or for tomographic techniques may be considered.

***Class C.*** CSL results are classified as *Highly Abnormal CSL Results*. The number of affected profiles with Class C occurrences and their location within the foundation element shall be reported for further evaluation. In addition to the evaluation steps noted for Class B CSL results, the Engineer of Record may require further evaluation of Class C results including excavation, chipping, or coring of the Class C zones and their remediation.

***Commentary:*** *A FAT increase corresponds to a wave speed reduction. Concrete strength can be related to the wave speed. Because the tubes might not be perfectly straight or even parallel, a fixed absolute limit of a wave speed value cannot be used for evaluation for perimeter profiles. Wave speed is best determined from the test results from the major diagonals. If the test is of young concrete and the average wave speed across the major diagonals is less than 10,000 ft/s, consideration should be given to repeating the test after a longer waiting time.*

**5.3 Tomography Analysis.** Tomography analysis shall be performed on the CSL test data of circular foundation elements if FAT increases result in a Class B CSL result in two or more profiles at the same elevation or a Class C CSL results in one profile. The Engineer may request additional tomography analyses to quantify the horizonal and vertical extent of any anomalous zones.

***Commentary*:** *Only wave speed is considered in tomography analyses. Therefore, Class B or C results identified solely from relative energy reductions cannot be further evaluated by tomography analysis. Additional offset scans (transmitter and receiver offset by 1 to 1.6 ft) may improve the analysis results showing more details for highly abnormal or conditional acceptable CSL results. Foundation shapes other than circular also cannot be evaluated by tomography analysis.*

**6.0 FOUNDATION INTEGRITY ACCEPTANCE**

The Engineer of Record shall have five working days to evaluate the results and determine whether the foundation element integrity is acceptable or not. The Contractor shall not perform any load testing or other construction associated with the foundation elements until after acceptance by the Engineer. If the element integrity is accepted by the Engineer, the Contractor may then proceed with construction. If the Engineer determines the element integrity is not acceptable, the element shall be cored, repaired, remediated, or replaced by the Contractor at the Contractor’s expense and with no increase in contract time.

**6.1 Post Test Remediation.** Specifications may require CSL access tubes to be filled with a structural non-shrink grout after CSL testing. If specified, the Contractor shall remove the water in the tubes, place a grouting tube to the bottom of each access tube, and fill each access tube with an approved grout mix.

***Commentary*:** *All CSL testing must be completed, and the foundation element accepted by the Engineer of Record before post-test grouting is performed by the Contractor.*

**7.0 MEASUREMENT AND PAYMENT**

**7.1 Basis of Measurement.** Crosshole Sonic Logging tests shall be measured per each foundation element tested and accepted, per linear foot, or per day of CSL testing.

**7.2 Basis of Payment.** The completed CSL results and report shall be paid for at the contract price for “Crosshole Sonic Logging” for each foundation element tested, per linear foot, or per day of CSL testing. This shall constitute full compensation for all costs incurred and relating to the CSL testing including, but not limited to procurement, preparation and installation, conducting the tests, and subsequent reporting of test results.

***Commentary:*** *Payment for CSL work on a “per day of testing” basis is considered the most equitable for all parties and is recommended.*

*Tomography analysis, if required, shall have an individual measurement and payment item on a per each basis.*

**REFERENCES**

ASTM D-6760, *Standard Test Method for Integrity Testing of Concrete Deep Foundations by Ultrasonic Crosshole Testing*. American Society of Testing and Materials, West Conshohocken, PA.

Deep Foundations Institute CSL Task Force, (2019). *Terminology and Evaluation Criteria of Crosshole Sonic Logging (CSL) as applied to Deep Foundations.* Deep Foundations Institute, Sparta, NJ