

Note: This sample specification contains recommended or typical quantities in parenthesis, in the format (quantity); the specifying Engineers can adapt these quantities for their particular construction projects. Contractual items are minimized since each agency has its own preferences and procedures.

Method overview of Crosshole Sonic Logging (CSL). By sending ultrasonic pulses through concrete from one probe to another (probes located in parallel tubes), the CSL procedure inspects the drilled shaft structural integrity of the concrete between the tubes, and extent and location of defects, if any. 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 transmitter and receiver. Dividing the distance between transmitter and receiver by the FAT value yields the approximate concrete wave speed which also is 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 6760, Standard Test Method for Integrity Testing of Concrete Deep Foundations by Ultrasonic Crosshole Testing. Standards are also available in many other countries.

(a) Personnel requirements for CSL.

- (1) **Qualifications of CSL Consultant.** The CSL Consultant shall have a licensed professional engineer supervising the testing and interpretation of results. The CSL Consultant shall be an independent testing agency with at least (3) years experience in CSL testing. The CSL Consultant qualifications and the specifications for the equipment used shall be submitted to the Engineer for approval prior to beginning drilled shaft installation.
- (2) **Assistance by the drilled shaft Contractor to the CSL Consultant.** The Contractor shall provide cooperative assistance, suitable access to the site and drilled shafts to be tested, and labor as required to assist the CSL Consultant in performing the required tests. Prior to testing, provide the drilled shaft lengths, tube lengths and positions, and drilled shaft construction dates to the CSL Consultant.

(b) Equipment requirements for CSL.

Provide a Cross Hole Analyzer manufactured by Pile Dynamics, Inc., (30725 Aurora Road, Cleveland, OH 44139, USA; <http://piledynamics.wpengine.com/>; email: info@pile.com; phone: +1 216-831-6131; fax +1 216-8310916), or an 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 inspection.

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

- (2) Ultrasonic transmitter and receiver 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 of at typically 1.5 to 2.0 inches diameter in the drilled shafts.
- (3) Two depth sensors to independently determine transmitter and receiver probe depths.
- (4) Triggering of the recording system time base with the transmitted ultrasonic pulse.

(c) CSL access tube preparation.

Install (number; typically a minimum of 4) access tubes in each (___ ft, m) diameter drilled shaft.

(Note: The actual number of tubes is often selected as one tube for every 0.25m to 0.35m (10 to 14 inches) of drilled shaft diameter, with a minimum of four access tubes. Drilled shafts with different diameters at the same site may require a different number of access tubes. Since actual cost of the tubes is very low compared to cost of the shaft, installing tubes in all shafts is highly recommended so that any shaft can later be tested if some difficulty is encountered during construction. Failing to install access tubes during installation would either prevent further testing or add significant costs for coring. It is generally not necessary to have more than eight access tubes per shaft.)

Every drilled shaft shall be equipped with access tubes to permit possible inspection by CSL. The number of drilled shafts to be tested by CSL is ([number] or [percentage of all drilled shafts]). The drilled shafts to be tested shall be chosen after installation by the Engineer. If significant defects are detected, the number of drilled shafts tested may be increased by the Engineer.

(Note: If only a percentage of shafts are tested, shafts should be selected for testing based on construction records. In addition, some shafts should be selected purely at random by the Engineer. When the foundation consists of groups of drilled shafts the percentage that should be tested per group increases when the number of shafts per group decreases. For sensitive or critical structures, or for those with minimal redundancy in the foundation, every shaft should be investigated.)

Nominal 38 mm (1.5 inch) or 50 mm (2.0 inch) inside diameter standard weight schedule 40 steel tubes or schedule 40 or 80 PVC pipes shall be provided for probe access in each drilled shaft (Schedule 80 PVC is preferred for longer tubes). 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 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 verify that unobstructed passage of the probes is achievable before the CSL Consultant arrives.

(Note: Experience suggests PVC tubes may be subject to “debonding” of the PVC with concrete in the upper part of the shaft, particularly if the shaft is cast under wet/slurry conditions. In such case, testing the shaft with PVC tubes should be done as soon as possible after casting to minimize debonding effects since debonding may invalidate the results.)

(Note: If an existing drilled shaft does not contain access tubes, access holes can be installed by coring a borehole in the concrete. Locate core holes about 150 mm or 6 inches inside the reinforcement cage. Log core holes and include descriptions of any inclusions or voids. For drilled shafts with access tubes which do not allow the probe to pass through the entire length of the tube due to poor workmanship, replacement access holes may be provided by core drilling.)

The tubes shall be fit with 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 to exceed (1.0m, 3 ft). Tubes shall be installed uniformly and equidistantly around the circumference 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 (150mm, 6 inches) of the bottom of the drilled shaft, to at least (1.0m, 3 ft) above the top of the concrete, and to at least (0.6m, 2 ft), but not more than (1.5m, 5 ft) above the ground surface. Tubes shall not be damaged during installation of the reinforcement cage.

(Note: Many specifications do not allow the tube to rest on the bottom of the drilled shaft excavation.)

After placement of the reinforcement cage, the access tubes shall be filled with clean fresh water as soon as possible but within at the latest (one) hours after concrete placement. Tube tops shall be capped to prevent debris from entering the access tubes. Do not apply excessive torque, hammering or other stresses which could break the bond between the tube and concrete when removing caps from the tubes.

(Note: The tubes should preferably be filled with water prior to concrete placement, but must be filled with water within at most 4 hours after placing concrete to prevent debonding of the access tubes due to differential temperatures. This is particularly important for PVC tubes.)

(d) Timing of the CSL test. The drilled shaft shall be tested no sooner than (3) calendar days after placement of all concrete in any drilled shaft, but within (10) days after placement and prior to loading for test drilled shafts, or within (45) days after placement on production drilled shafts.

(Note: CSL testing can be performed any time after concrete installation when concrete has obtained sufficient strength (e.g. 66% of design $f'c$), although 2 days is usually the

minimum acceptable wait. 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 drilled shafts or even as a function of depth in a single drilled shaft. However, if PVC tubes are used for wet cast shafts (e.g. cast under slurry), long wait times increase the tube debonding which is detrimental to the test. Production drilled shaft installation and subsequent construction influence the dates of CSL testing.)

(Optional insertion: After all CSL testing has been completed, and after acceptance of the drilled shaft by the Engineer, the Contractor shall remove the water in the tubes, place grout tubes extending to the bottom of the access tube, and fill all access tubes in the drilled shafts with grout.)

(e) CSL procedure. Prior to CSL testing, the Contractor shall provide the Engineer and CSL Consultant with a record of all drilled shaft lengths with elevations of the top and bottom, and installation dates of all drilled shafts. The access tubes shall be clearly labeled for identification by the CSL Consultant.

The CSL testing shall be performed with the transmitter and receiver probes in the same horizontal plane in parallel tubes unless test results indicate potential defects, in which case the questionable zone may be further evaluated with angled tests (source and receiver vertically offset in the tubes) at least for perimeter pairs of tubes. Using the labeling established for the tubes, CSL testing shall be performed between all adjacent perimeter access tube pairs and across at least all major diagonals within the drilled shaft. In the event that defects are detected in drilled shafts with more than four tubes, additional logs in other diagonal tube pairs may be required to estimate the extent of the defect.

Probes shall be lowered from the top, effectively measuring the access tube lengths. Probes shall be pulled simultaneously, with CSL measurements taken at intervals of 50 mm (2 inches) or less from the bottom to the top of the drilled shaft. Defects indicated by late pulse arrival times and significantly lower amplitude/energy signals shall be immediately reported to the Engineer. Additional tests such as the offset elevation CSL testing may be required by the Engineer to further evaluate the extent of such defects. If debonding between the access tube and the concrete is indicated by the CSL results, an alternative test method shall be required to determine the integrity of the concrete in the debonded region.

(Note: In case defects are detected, additional tests or analysis options may include CSL tomography, gamma-gamma nuclear density logging, sonic echo or impact response tests, high strain dynamic pile testing, static load testing, or concrete coring. If the drilled shaft is cored, an accurate log of the cores which include depth and core recovery shall be kept, and core and coring logs shall be properly identified and given to the Engineer. Debonding can sometimes be corrected by flooding the top of the shaft with water.)

(f) CSL results. Results of the CSL shall be presented in a written report within (5) working days of completion of testing. The report shall include presentation of CSL logs for all tested tube pairs including:

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.

A CSL log shall be presented for each tube pair. The rating of the shaft integrity considers the increases in “first arrival time” (FAT) and the energy reduction relative to the arrival time or energy in a nearby zone of good concrete.

The criteria for evaluation of the concrete from the CSL test shall follow:

Satisfactory	(G) (Good)	FAT increase 0 to 10% <u>and</u> Energy Reduction < 6 db
Anomaly	(Q) (Questionable)	FAT increase 11 to 20% <u>and</u> Energy Reduction of < 9 db
Flaw	(P/F) (Poor/Flaw)	FAT increase 21 to 30% <u>or</u> Energy Reduction of 9 to 12 db
Defect	(P/D) (Poor/Defect)	FAT increase >31% <u>or</u> Energy Reduction > 12 db

Flaw or Defect zones, if any, shall be indicated on the logs, listed in a table, and their horizontal and vertical extent and location discussed in the report text. Flaws must be addressed if they affect more than 50% of the profiles. Defects must be addressed if they affect more than one profile (a profile is the result of complete investigation from bottom to top between two tubes) at the same cross section. Flaws or Defects covering the entire cross section define a full layer concern requiring repair. “Addressing” a Flaw or Defect means as a minimum an evaluation by tomography if the concern is localized (e.g. not across the full section), and/or, depending on the depth to the concern, additional measures like core drilling, repair or replacement, repeat tests after a longer waiting time or testing by other methods (gamma-gamma, low strain, high strain).

(Note: 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. It should also be noted that if the referenced good concrete exceeds the specifications, then a concrete with a local 20% wave speed reduction might still exceed the specifications. If the test is of young concrete and the average wave speed across the major diagonals is less than 3,000 m/s (10,000 ft/sec), consideration should be given to repeating the test after a longer wait to assure the concrete has good strength.)

The log for each pair of tubes shall be clearly identified and oriented relative to the structure. The Engineer shall have (5) working days to evaluate the results and determine whether the drilled shaft construction is acceptable or not. The Contractor shall not perform any load testing or other construction associated with these drilled shafts until after acceptance by the Engineer. If the drilled shaft is accepted by the Engineer, the Contractor may then proceed with construction. If the Engineer determines the drilled shaft is not acceptable, the drilled shaft shall be cored, repaired or replaced by the Contractor at the Contractor's expense and with no increase in contract time.

(g) Basis of Payment. The completed CSL results and report shall be paid for at the contract bid price for "Crosshole Sonic Logging" (for each drilled shaft, per linear ft or meter, or per day of 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 results.

(Note: payment for CSL work on a "per day of testing" basis is considered the most equitable for all parties and is recommended.)