Post Installation

Lesson 8

ODOT MATERIALS & INSPECTION

Learning Objectives

- Discuss when the contractor may proceed with subsequent shaft construction (after completing the first shaft)
- Verify if Contractor is in compliance with tolerance criteria
- Identify and describe various integrity and load tests
- Discuss how to complete the Drilled Shaft Inspection Report

ODOT Standard Specifications
00512.49 Scheduling and Restrictions

Unless otherwise approved, do not proceed with construction of subsequent shafts until the CSL testing has been completed on the first drilled shaft and the results have been approved and accepted, in writing by the Engineer.

00512.49 Scheduling and Restrictions – Unless otherwise approved, do not proceed with construction of subsequent shafts until the CSL testing has been completed on the first drilled shaft and the results have been approved and accepted, in writing by the Engineer. Approval to proceed with the construction of subsequent shafts, before receiving approval of the first shaft will be based on the Engineer's observations of the Contractor's workmanship during construction of the first shaft and the Engineer's review and assessment of the following:

- The Contractor's conformance with the approved shaft installation plan.
- The Contractor's daily reports and inspector's daily logs of excavation, rebar, and concrete placement.
- The concrete placement logs and volume curves.

ODOT Standard Specifications
00512.49 Scheduling and Restrictions

Approval to proceed with the construction of subsequent shafts, before receiving approval of the first shaft will be based on the Engineer's observations of the Contractor's workmanship during construction of the first shaft and the Engineer's review and assessment of the following:

- The Contractor's conformance with the approved shaft installation plan.
- The Contractor's daily reports and Inspector's daily logs of excavation, rebar, and concrete placement.
- The concrete placement logs and volume curves.

ODOT MATERIALS & INSPECTION

Approval to proceed with subsequent shafts (after the first one is constructed) will be based largely on the inspector's records and observations as to how well the contractor followed the shaft installation plan and whether there were any problems or issues observed during construction of the first shaft.

ODOT Standard Specifications
00512.49 Scheduling and Restrictions

- Written notification will be provided to the Contractor on whether or not to proceed with subsequent shaft construction within 24 hours after completion of the first shaft.
- If the Engineer determines the first shaft to be of questionable quality, discontinue all shaft construction until the CSL test results of the first shaft are received and reviewed and the shaft accepted, in writing, by the Engineer.

00512.49 Scheduling and Restrictions – (continued)

Written notification will be provided to the Contractor on whether or not to proceed with subsequent shaft construction within 24 hours after completion of the first shaft. If the Engineer determines the first shaft to be of questionable quality, discontinue all shaft construction until the CSL test results of the first shaft are received and reviewed and the shaft accepted, in writing, by the Engineer.

Denial of permission to proceed with subsequent shaft construction will not be cause for contract time extension.

ODOT Standard Specifications
00512.49 Scheduling and Restrictions

- Do not proceed with the third drilled shaft until the final CSL test results from the first drilled shaft has been received and reviewed and the shaft accepted, in writing, by the Engineer.
- After the first drilled shaft on the Project has been accepted, make no significant changes in construction methods, equipment, or materials used to construct subsequent shafts, unless otherwise approved.

00512.49 Scheduling and Restrictions – (continued)

Do not proceed with the third drilled shaft until the final CSL test results from the first drilled shaft has been received and reviewed and the shaft accepted, in writing, by the Engineer.

After the first drilled shaft on the Project has been accepted, make no significant changes in construction methods, equipment, or materials used to construct subsequent shafts, unless otherwise approved.

Learning Objective

Describe when the contractor may proceed with subsequent shaft construction

- No problems with the first shaft
- After review of:
  - The Contractor's conformance with the approved shaft installation plan.
  - The Contractor's daily reports and Inspector's daily logs of excavation, rebar, and concrete placement.
  - The concrete placement logs and volume curves.

Drilled Shaft Tolerance Criteria

- Horizontal Position
  (at the Plan Elevation of the Top of Shaft)
- Top Elevation of Shaft Concrete
- Vertical Alignment in Soil
- Vertical Alignment in Rock
- Top Elevation of Steel Reinforcement

ODOT MATERIALS & INSPECTION

00512.42 Construction Tolerances – Excavate drilled shafts as accurately as possible at the locations shown and within the specified tolerances listed below. Determine the drilled shaft dimensions and alignment with approved methods. The following construction tolerances apply to drilled shafts unless otherwise stated:

Horizontal Position (At the Plan Elevation of the Top of Shaft):

- **Shaft Diameter Less Than or Equal to 6 Feet** – 3-inch horizontal tolerance from the location shown.
- **Shaft Diameter Greater Than 6 Feet** – 6-inch horizontal tolerance from the location shown.

Top Elevation of Shaft Concrete:

- **Top Elevation Above Water** – Minus 3 inches to plus 1 inch from the plan top of shaft elevation.
- **Top Elevation Under Water** – Minus 3 inches to plus 6 inches from the plan top of shaft elevation.

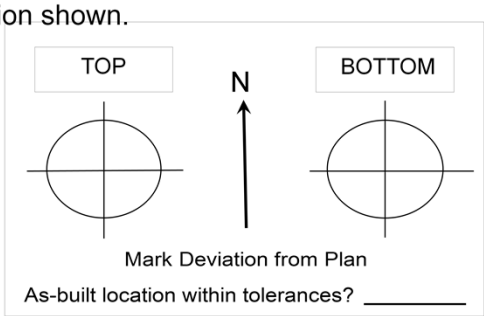
Vertical Alignment in Soil – May not vary from the plan alignment by more than 1.5% of the shaft length.

Vertical Alignment in Rock – May not vary from the plan alignment by more than 2% of the shaft length.

Top of Steel Reinforcement – Plus or minus 6 inches from the plan top of steel reinforcement elevation.

Drilled Shaft Tolerance Criteria –
Horizontal Position at the Plan Top Elevation of the Shaft

- **Shaft Diameter less than or equal to 6 feet** – 3-inch horizontal tolerance from the location shown.
- **Shaft Diameter greater than 6 feet** – 6-inch horizontal tolerance from the location shown.



00512.42 Construction Tolerances – Excavate drilled shafts as accurately as possible at the locations shown and within the specified tolerances listed below. Determine the drilled shaft dimensions and alignment with approved methods. The following construction tolerances apply to drilled shafts unless otherwise stated:

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- **Shaft Diameter Less Than or Equal to 6 Feet** – 3-inch horizontal tolerance from the location shown.
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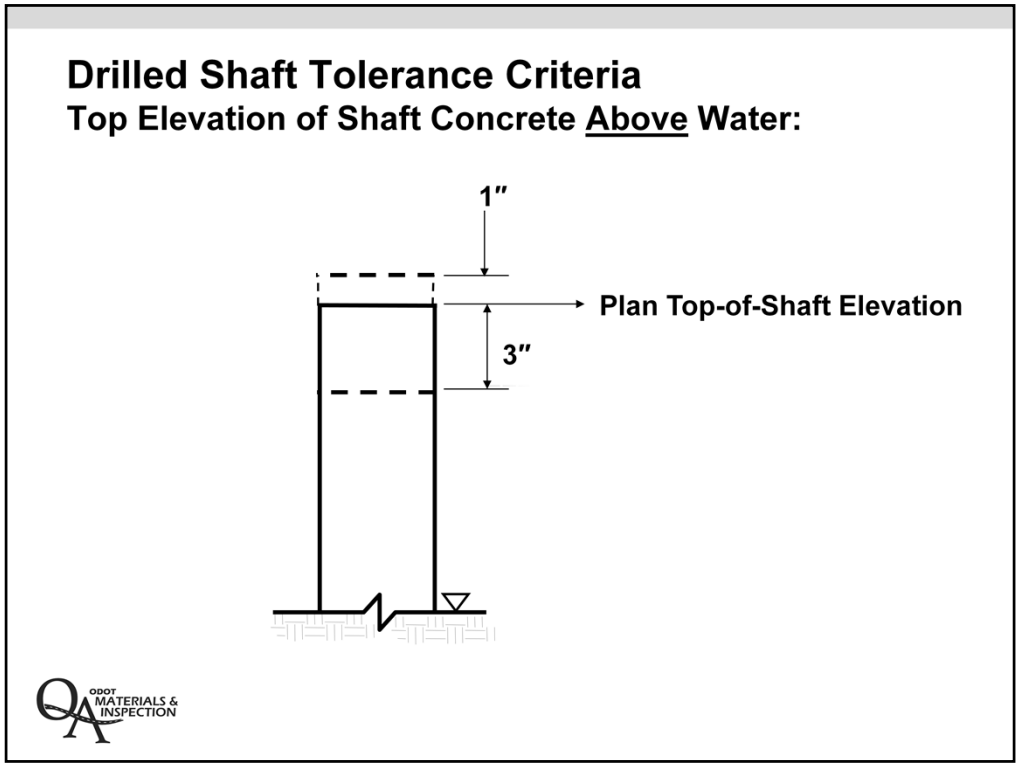
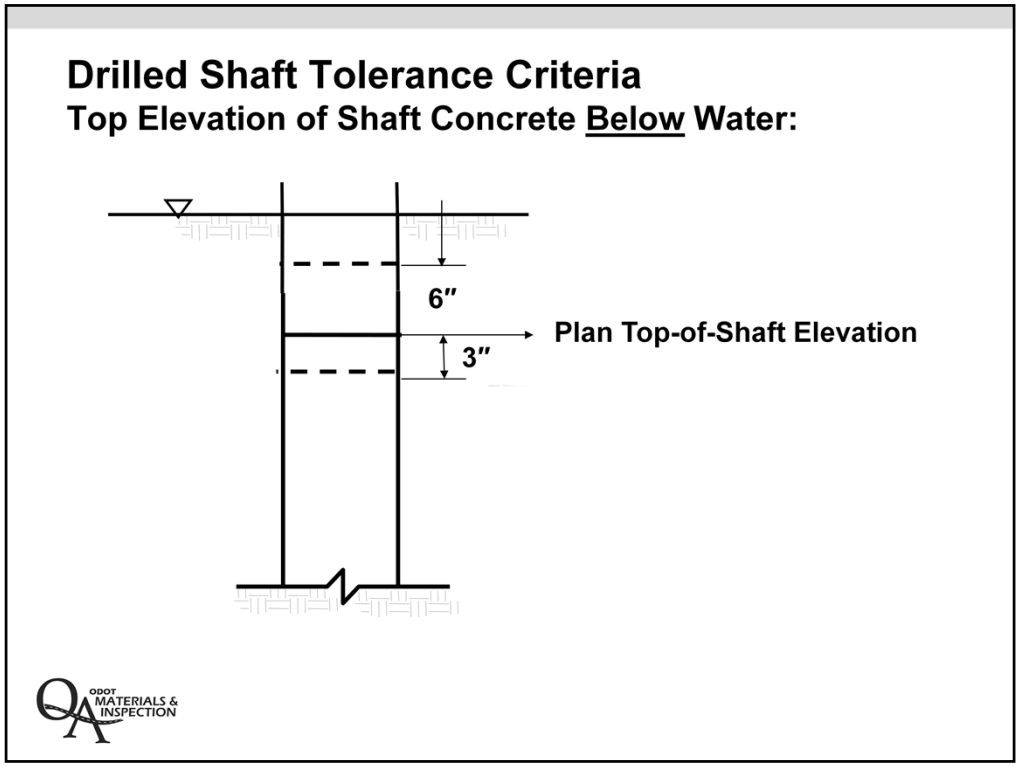


00512.42 Construction Tolerances –

Top Elevation of Shaft Concrete:

- **Top Elevation Above Water** – Minus 3 inches to plus 1 inch from the plan top of shaft elevation.
- **Top Elevation Under Water** – Minus 3 inches to plus 6 inches from the plan top of shaft elevation.



00512.42 Construction Tolerances –

Top Elevation of Shaft Concrete:

- **Top Elevation Above Water** – Minus 3 inches to plus 1 inch from the plan top of shaft elevation.
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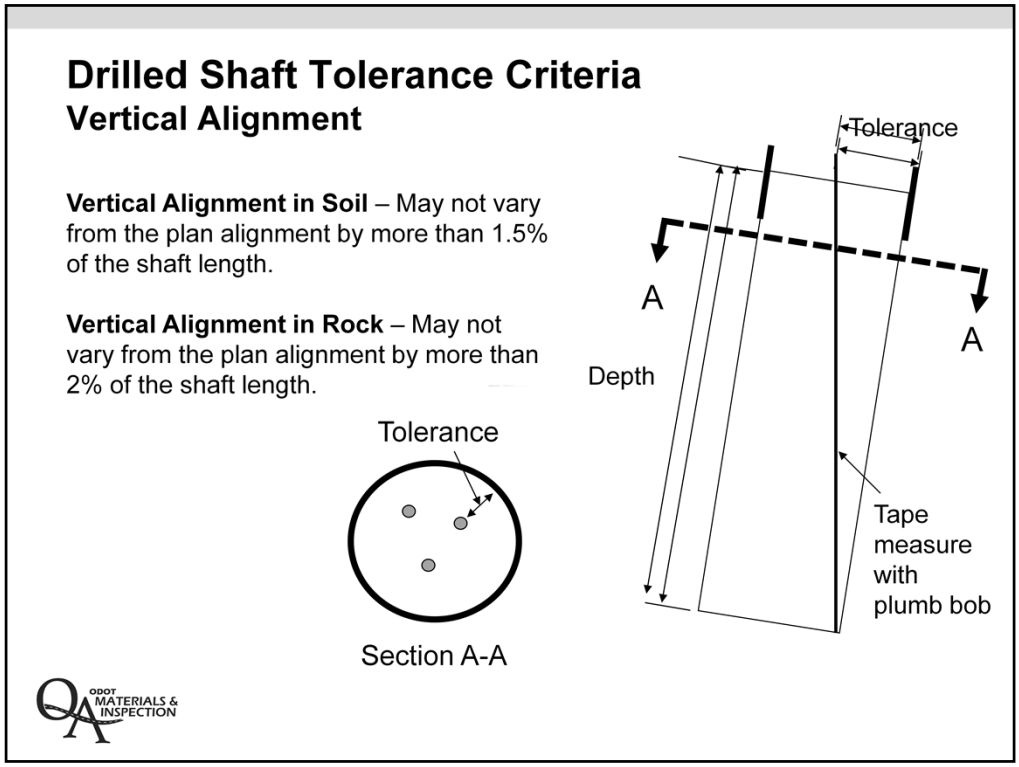
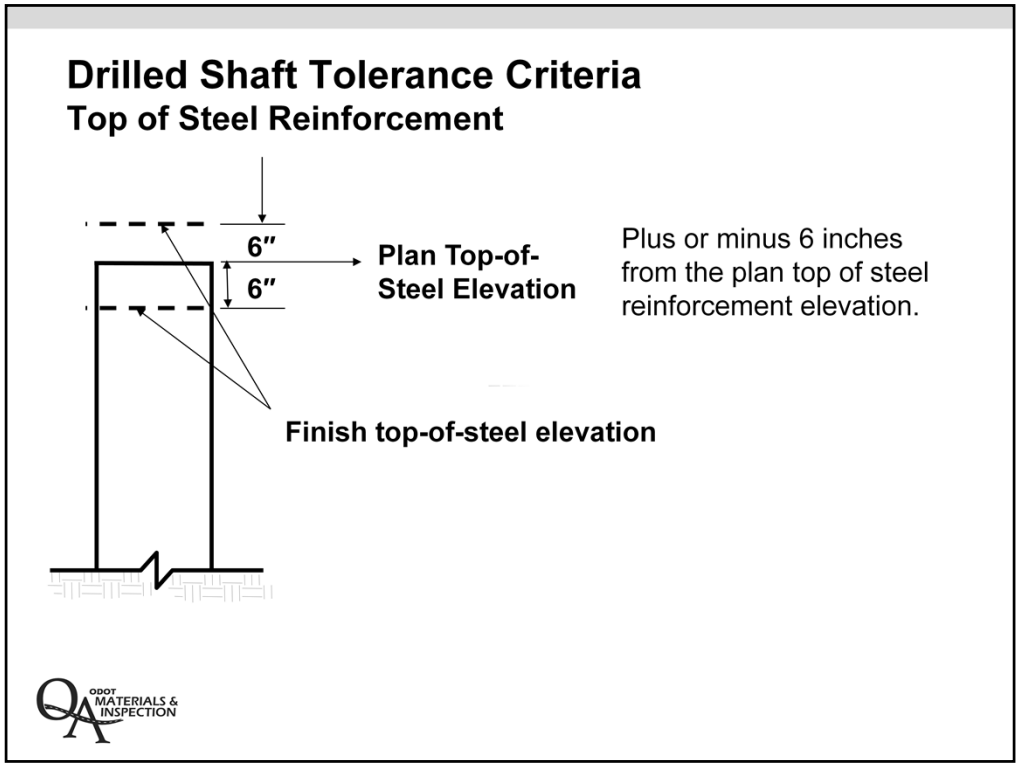


00512.42 Construction Tolerances –

Vertical Alignment in Soil – May not vary from the plan alignment by more than 1.5% of the shaft length.

Vertical Alignment in Rock – May not vary from the plan alignment by more than 2% of the shaft length.



00512.42 Construction Tolerances –

Top of Steel Reinforcement – Plus or minus 6 inches from the plan top of steel reinforcement elevation.

Learning Objective

Verify if Contractor is in compliance with tolerance criteria

- Horizontal position
  (at the Plan Elevation of the top of shaft)
- Top elevation of shaft concrete
- Vertical alignment in soil and in rock
- Top of steel reinforcement

These “as-constructed” elevations and positions should be recorded on the Drilled Shaft Inspection Report.

Potential Problems with Constructed Shafts

- Folded-in debris in concrete – excessive sand being carried by the slurry and sedimentation of cuttings from the slurry column.
- Soft shaft bottom – incomplete bottom cleaning.
- Caving of the sidewalls.
- Temporary casing that cannot be removed – In some cases, the crane or other equipment handling the casing doesn't have the power to pull the casing out.
- Horizontal separation or severe necking – This can occur if the concrete sets too early and temporary casing has concrete adhering to it when pulled.

The vast majority of drilled shafts are constructed routinely, without difficulty, and are sound structural elements. Occasionally defects in the completed shaft can be introduced during the construction process through errors in handling of slurry, concrete, casings, cages and other factors.

Therefore, tests to evaluate the soundness or integrity of the shaft are conducted. These become even more critical when difficult drilling and installation problems were encountered.

These tests may include a variety of down-hole access tube tests, including Cross-hole acoustic logging and gamma-gamma logging, or a less expensive Sonic Echo test. The goal of these integrity tests are to determine if defects, or anomalies, exist within the constructed shaft.

Dirty Hole

Very large defect found by Sonic Echo test.

Probably due to dirty hole.

No concrete.

This is a photograph of a defect on a highway bridge after contaminated concrete had been chipped away. A severe defect of this size can be detected with almost certainty by integrity testing methods.

Post Construction Testing

- **Integrity Tests**
  To evaluate the soundness or “structural integrity” of the constructed shaft.
- **Load Tests**
  To determine if the shaft, as constructed, will carry the required design loads.

Integrity testing is essentially another term for non-destructive testing and is commonly used in ODOT to determine the quality and structural integrity of completed shafts.

Load tests are conducted to determine the load carrying capacity of the shaft. These tests are usually done under a separate contract prior to the main bridge construction contract so the information obtained can be used in design. However, sometimes load tests are performed on production shafts to verify capacity and assumptions made in design.

Integrity Tests

- The purpose of post-construction integrity testing is quality assurance of concrete placement.
- Most tests used for this purpose have no permanent effect on a drilled shaft and are therefore referred to as “non-destructive tests”, or NDT.
- NDT results are used in “nondestructive evaluation”, or NDE, in combination with construction observations, inspection records and other quality control assurance measures to assess shaft acceptance.
- NDE provides a tool for ensuring the as-built foundation satisfies the construction specifications and will perform as assumed in the design.

ODOT MATERIALS & INSPECTION

Integrity Tests

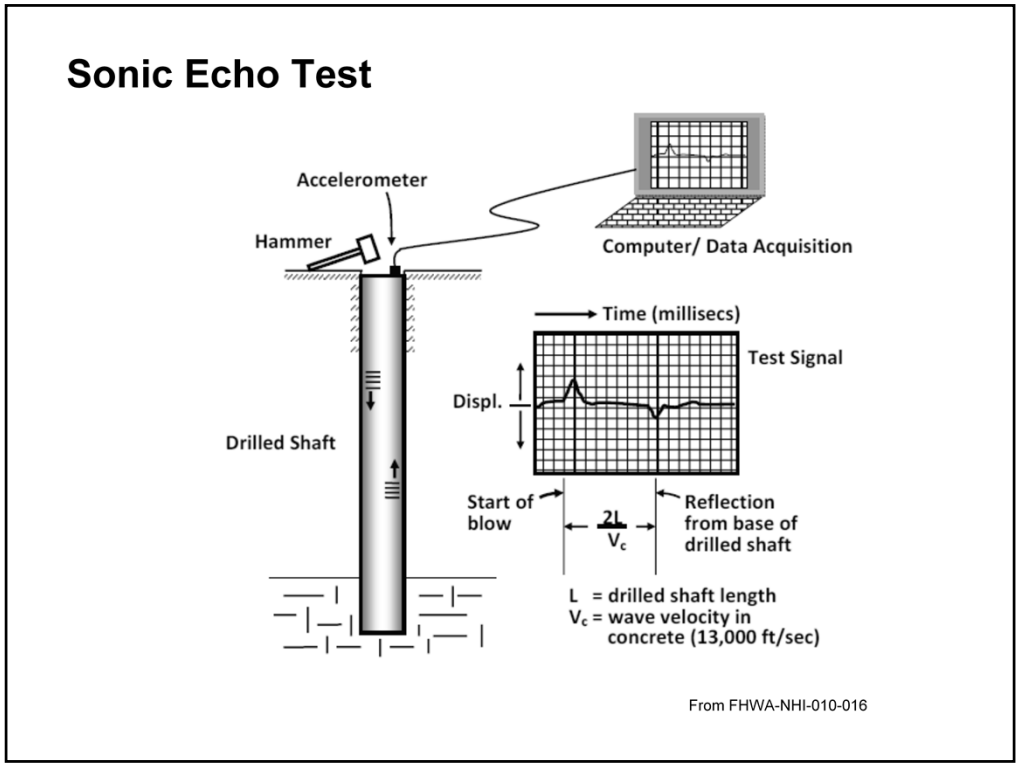
- Sonic echo / impulse-response
- Crosshole sonic log (acoustic)
- Gamma-gamma
- Thermal integrity

Tests are run by trained and experienced personnel, using specialized equipment and software.

Crosshole Sonic Log (CSL) testing is the main nondestructive testing (NDT) performed on drilled shafts in ODOT. Other NDT testing methods such as gamma-gamma and sonic-echo testing are available but are less used in OODT.

Thermal integrity testing is a relatively new method for testing shaft integrity and has yet to be implemented into ODOT practice.

These tests generally require expert knowledge for performance and interpretation. Technician-level expertise is required for conducting the field tests, while interpretation of results should be done by a qualified engineer in consultation with the project geotechnical engineer. Most of these tests also require specialized software for data acquisition and processing.



Not currently used by ODOT. The Engineer could ask for it in situations where you don't have CSL tubes.

This is a schematic of a pulse-echo (sonic-echo) test. The principle is obvious from the sketch. Advantages of the test are that it can be done on virtually any shaft without prior planning (no access tubes need be placed in the shaft) and is quick and inexpensive. Disadvantages are that is prone to showing false positives and to missing fairly large voids or inclusions in the concrete. It is essentially 100 per cent accurate only if the void or inclusion covers about half of the cross-sectional area of the shaft and is reasonably thick (say 20″ or thicker) and the test is performed correctly. This test is not usually effective in locating deep defects (depth > 65 ft.) and cannot detect contact problems between the concrete and the soil or rock. The apparatus to perform this test is available commercially, and numerous consultants provide this service. However, consultant service varies widely in quality. False positives in this method come from changes in cross-section that are not associated with an anomaly, from changes in concrete modulus (such as at the interface between concrete placed from two different trucks), from changes in the stiffness of the soil or rock surrounding the shaft, which also dissipate sonic energy, and from testing technique errors such as setting the sensor on weak or powdery concrete.

The test is performed in accordance with ASTM D5882.

Sonic Echo Test

This is a photo of a sonic-echo test being performed. Note that the technician has embedded a nail in the top o f the shaft's concrete so as to provide a sharp sonic wave. This will help find small defects near the top of the shaft. To search for deeper defects, a larger hammer with a hard cushion might be used to produce a sonic compression wave of longer length that will propagate deeper (but with less resolution) that the sharp wave.

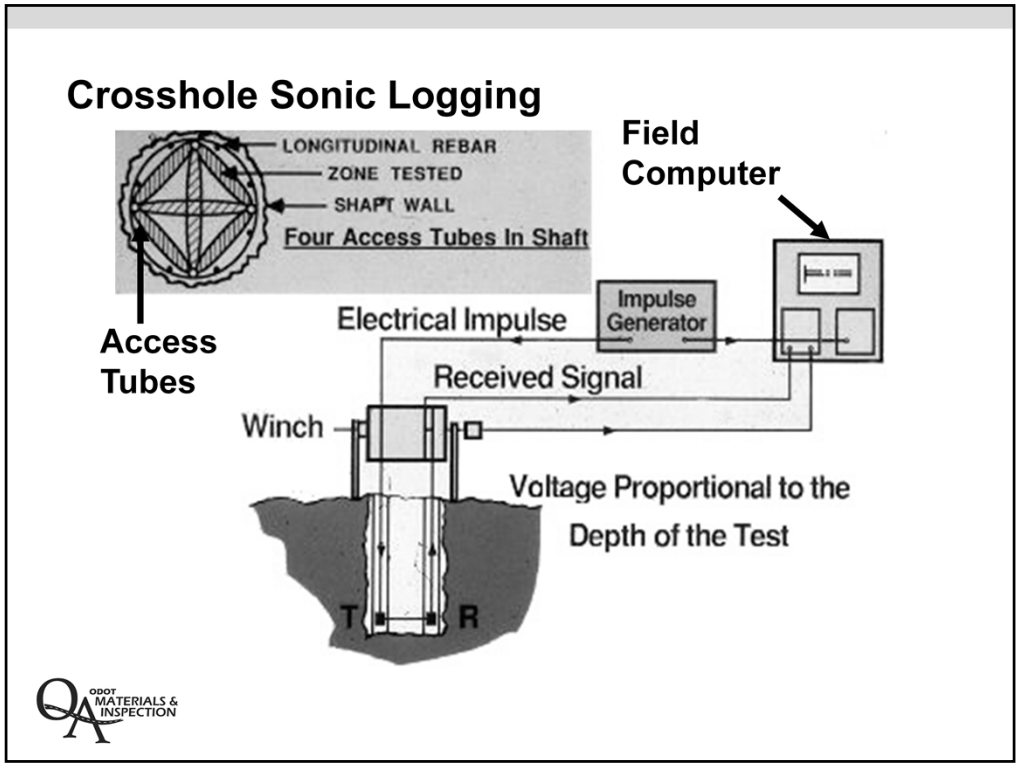
Crosshole Sonic Log (CSL) Test

- Primary integrity test method used in ODOT
- Conducted according to ASTM D6760
- Required on nearly all drilled shaft jobs
- Contractor typically supplies personnel to perform the testing

ODOT Standard Specifications

00512.48 Drilled Shaft Testing and Acceptance – Acceptance of drilled shafts will be based on the Engineer's review of the results of CSL, or other, integrity testing (if conducted), field inspection reports and visual observations during drilled shaft construction. The Engineer has final authority on the approval of drilled shafts. For shafts that are integrity tested, the Engineer will determine final acceptance of each tested shaft, based on the integrity test results and inspection reports and will provide a response to the Contractor within 5 calendar days after receiving the CSL test report.

The amount of CSL testing required should be specified in the Special Provisions for each project.



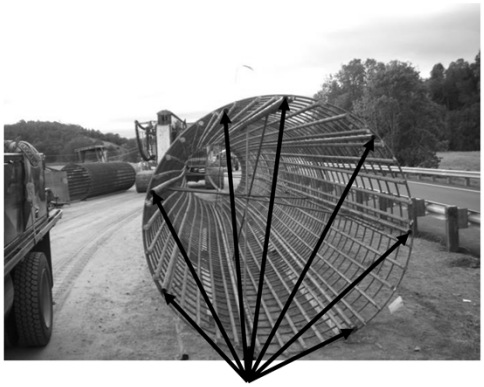
A primary use of access tubes is in the performance of cross-hole acoustic tests (usually ultrasonic in air but sonic in concrete), sometimes called cross-hole sonic log tests or CSL tests. Several access tubes are placed regularly around the circumference of the cage. One per foot of shaft diameter is a good rule of thumb. “Shots” are made from a source that generates acoustic energy to an energy receiver in another tube at the same elevation, as depicted here. Both the time of travel from the source tube to the receiver tube and the amount of energy transferred between tubes are indicators of the presence of either sound concrete or defective concrete. Good coverage of the interior of the cage can usually be achieved, as shown in the upper left side. However, little information on concrete outside the cage can be obtained.

Several variations on this method are practiced by highly skilled specialists, involving placing source and receiver at different elevations to develop a three-dimensional profile of the interior of the shaft, in a process referred to as tomography.

This method can be performed fairly quickly and is often more definitive than the sonic-echo method or its derivatives. With this method it is a good idea to use tubes made of a material that expands and contracts thermally with concrete. Schedule 40 steel tubes fit this requirement and are recommended. PVC tubes do not and may debond from the concrete, although if a test is performed soon after the concrete sets (usually within seven days but not sooner than three), the bonding may remain strong enough for the requisite passage of the sonic waves. In order to help maintain bond between the tubes and concrete and to couple the transmitter and receiver to the concrete, the tubes should be filled with water soon after the concrete is placed.

Crosshole Sonic Log (CSL) Test

- Check that CSL tubes were installed as per the plans and filled with water and capped within I hour after the concrete pour is completed.
- Before testing, check to see that the water level in the tubes has not dropped.



CSL Tubes, straight and parallel

Crosshole sonic log testing requires access tubes cast into the shaft concrete and attached inside the steel cage. The access tubes for CSL testing are always steel to provide the best possible bond between the tube and the concrete. These tubes need to be cast into the concrete at the time of construction. The tubes must be filled with water to dissipate heat from concrete curing process. Without water in the tubes they may debond from the concrete rendering them useless for testing.

It is very important that the tubes are installed on the proper spacing and maintain a straight alignment the full length of the shafts. The results of the test are affected by the distance between each pair of tubes.

Different tests require different types of tubes (e.g., PVC for gamma-gamma versus schedule 40 steel for CSL). Some tests require that the tubes are filled with water, and some don’t.

These are the source and receiver devices that are passed down the access tubes in a CSL test. The material specifications for the CSL access tubes are as follows:

00512.15 Crosshole Sonic Log (CSL) Access Tubes - Furnish steel crosshole sonic log (CSL) access tubes meeting the following requirements:

Steel access tubes shall be at least 1 1/2 inch inside diameter Schedule 40 pipe conforming to ASTM A 53, Grade A or B, Type E, F, or S.

Use access tubes having a round, regular inside diameter free of defects and obstructions, including all pipe joints, in order to permit the free, unobstructed passage of the source and receiver probes used for the testing. Ensure that access tubes are watertight, free from corrosion with clean internal and external faces to ensure good bonding between the drilled shaft concrete and the access tubes. Fit the access tubes with watertight caps on the top and bottom.

Access tube acceptance will be based on manufacturer's certification that the furnished material meets the requirements of this Specification.

This is a CSL test conducted in a shaft with a non-contact splice zone. The test is conducted after the first shaft concrete pour which is from the bottom of the shaft up to the bottom of the transition (non-contact splice) zone. The CSL testing is done here so, if a defect is found in the shaft, it can be more easily repaired without the column steel in the way.

Usually CSL tests should be conducted in all tube combinations. The formula to calculate the number of combinations possible is:

Total Combinations = n(n-1)/2; where “n” is the number of tubes.

Personnel performing the testing should be qualified and approved in accordance with the Personnel Qualifications Submittals.

Make sure to document the time between the end of the shaft pour and the testing.

Crosshole Sonic Log (CSL) Test

- CSL testing is not always a conclusive test and the results often require interpretation and further in-depth review by the geotechnical and structure engineers.
- The results can sometimes be misleading.
- The CSL test results are used along with the concrete volume graphs, excavation logs and other shaft construction records to determine shaft acceptance.

ODOT Standard Specifications

00512.48 Drilled Shaft Testing and Acceptance –

(a) Crosshole Sonic Log Testing – Provide crosshole sonic log testing equipment and perform crosshole sonic log testing and analysis on the first drilled shaft completed at each structure and subsequent shafts as specified or designated for testing by the Engineer. Provide CSL testing equipment conforming to the requirements of ASTM D 6760 and approved by the Engineer. Provide all necessary access and other support to the CSL testing firm necessary to do the CSL testing work.

Unless otherwise directed, perform one CSL test on each shaft designated for testing. A single CSL test consists of all ultrasonic profile combinations in a given shaft. Test completed drilled shaft foundations using Ultrasonic Crosshole Testing methods (Crosshole Sonic Log (CSL) Testing) according to ASTM D 6760. Inform the Engineer of scheduled CSL testing at least three calendar days prior to the testing. Perform all CSL testing using the Contractor's CSL technician in the presence of the Engineer.

Allow at least three calendar days of curing time before testing unless otherwise approved. Additional curing time beyond three calendar days may be required if the shaft concrete contains admixtures such as set retarding admixture or water reducing admixture. Additional CSL testing required due to the CSL testing being conducted on concrete that has not cured sufficiently is at no additional cost to the Agency. Additional curing time required due to concrete admixtures will not be grounds for additional compensation or time extensions.

Crosshole Sonic Log (CSL) Test

Procedures to use when conducting CSL testing for quality control of drilled shafts on ODOT projects.

- Contractor provides the CSL subcontractor to do the testing (SP 00512). This is included in the contract with a bid item for the number of CSL tests per bridge.
- CSL testing performed according to ASTM D6760-02
- CSL testing is performed on the first shaft constructed and others as described in the Special Provisions.
- Additional shafts are tested if construction methods change or shaft construction results in questionable quality shafts. This is especially true for uncased shafts, excavated below the water level in soils.

ODOT Standard Specifications

00512.48 Drilled Shaft Testing and Acceptance –

(b) Contractor's CSL Test Reports - Provide a brief summary report of the data, with interpretation of the test results, to the Engineer at the completion of each test. Provide copies (either hardcopies or electronic files) of the raw test data as requested. Mark the test data files to identify, as a minimum, the structure, bent and shaft number, the date of CSL testing, depths of testing and any other pertinent information.

Crosshole Sonic Log (CSL) Test Reports

- Submit three copies of a final CSL Test Report for each shaft tested.
- Submit all reports to the Engineer within five calendar days of the performance of the tests.
- Provide electronic file copies of the raw CSL data measurements, if requested.

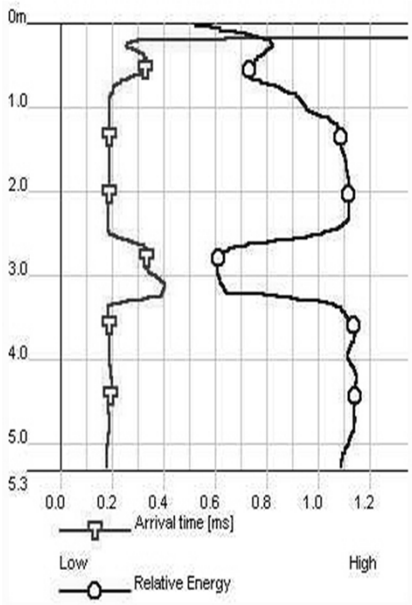
ODOT Standard Specifications

00512.48 Drilled Shaft Testing and Acceptance –

(b) Contractor's CSL Test Reports (continued)

Submit three copies of a final CSL Test Report for each shaft tested according to ASTM D 6760. Provide electronic file copies of the raw CSL data measurements if requested. The report shall summarize the CSL testing performed, data analysis, and interpretation of CSL data with special attention made to the identification and location of any anomalies or possible defects. Provide interpretation of the CSL test data in terms of overall shaft integrity and acceptance. Submit all reports to the Engineer within 5 calendar days of the performance of the tests.

Crosshole Sonic Log Test Results

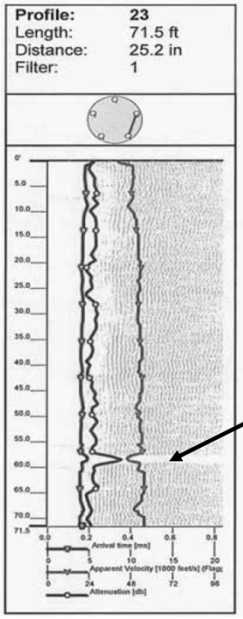


A CSL data plot is shown on the right for a shaft that has a defect in it. At this location (about 10 feet deep) the arrival time of the sonic wave (red line) increased dramatically while the relative energy of the signal (blue line) decreased at the same location. The increase in arrival time indicates a decrease in signal velocity through the concrete and a possible defect since acoustic signals travel slower through contaminated concrete, soil or air. In general a decrease in velocity greater than 20% indicates the likelihood of a defect.

CSL test results should be forwarded to Bridge Designer and the Geotechnical Engineer for review, regardless of what the CSL report from the Contractor says. Both engineers should concur that the shaft is acceptable or needs further investigation.

Structural and/or geotechnical analysis may be necessary at this point to assess the load carrying capacity of the shaft based on interpretation of the CSL test results.

Crosshole Sonic Log Test Results



Sample CSL Profile

- Profile name designated by the tube number in each pair, tubes are numbered clockwise from the top
- Depth is from the top of concrete
- Distance is distance between tubes

Anomaly (possible defect) at 59 feet

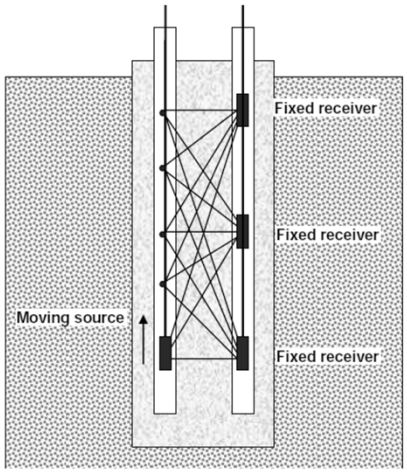
- Increase in arrival time (red)
- Decrease in velocity (green)
- Reduced energy blocks out stacked wave form plot

This is a CSL data plot for one tube combination from a CSL report. It shows a possible defect. This profile would be evaluated along with others from the same shaft and inspection records to determine shaft acceptance.

Velocity Reduction, VR (%)	Signal Distortion/Strength	Concrete Rating	Indicated Conditions
0 – 10	none/normal energy reduction ≤ 6 dB	Good (G)	Acceptable quality concrete
10 – 20	minor/lower energy reduction 6.1 to 9 dB	Questionable (Q)	Minor contamination, intrusion, or questionable quality concrete
> 20	severe/much lower energy reduction > 9 dB	Poor/defect (P/D)	contamination, intrusion, and/or poor quality concrete
No signal	None	No Signal (NS)	Intrusion or severe defect; could also be caused by tube debonding
≈ 60	severe/much lower energy reduction ≥ 12 dB	Water (W)	water intrusion or water-filled gravel intrusion with few or no fines

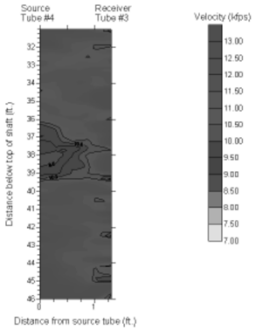
Source: FHWA Drilled Shafts Manual, (FHWA-NHI-10-016

Crosshole Tomography Testing



Takes a large number of vertical offset measurements and numerous tube pair combinations.

Two or three dimensional images of signal (tomograms) can be generated.



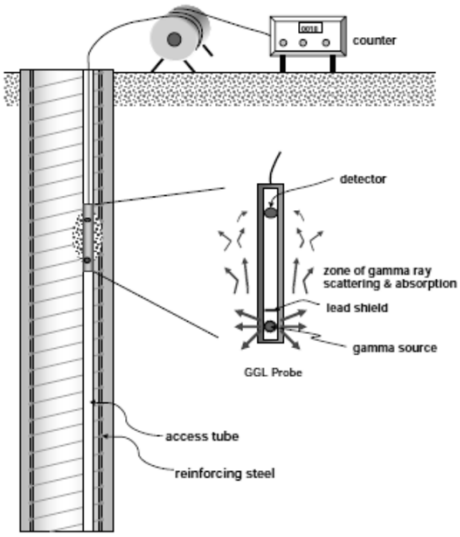
Sample 2D Tomogram

The Crosshole Tomography (CT) method is based on the same principles as CSL and utilizes the same equipment and access tubes. CT differs from conventional CSL in the way measurements are obtained and in processing of the data. Measurements are made for a larger number of transmitter-receiver locations, including measurements for which the transmitter and receiver are at different elevations (vertical offset). Typically the receiver probe is positioned at a fixed elevation in one tube while the transmitter elevation is varied in one of the other tubes. Measurements are made for numerous combinations of vertical offset and for all possible tube combinations. It is typical for measurements in a single shaft to involve tens or hundreds of transmitter-receiver combinations, resulting in the generation of data for thousands of ray paths.

Vertical or horizontal slices of the shaft showing the test results may be generated and the tomograms (either 2D or 3D) can show the extent of pronounced zones of low velocity material, indicating weaker concrete or soil inclusions.

CT can be conducted after, or even during, the initial CSL testing to further define areas or zones of questionable concrete.

Gamma-Gamma Test

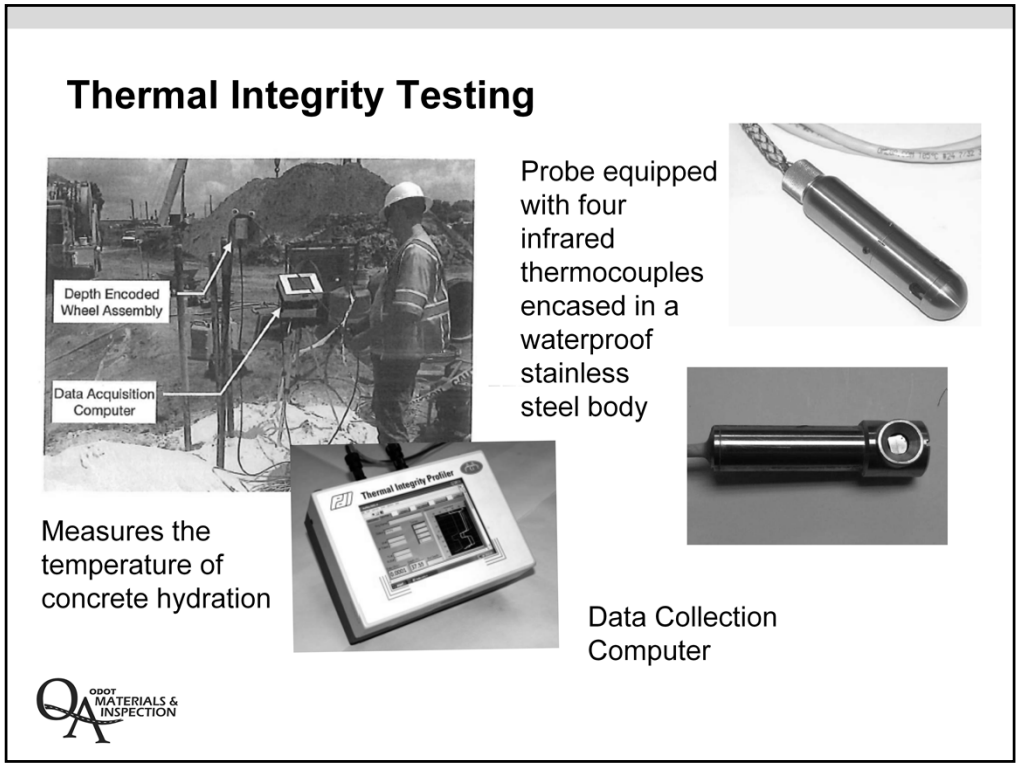


From FHWA-NHI-010-016

Another successful down-tube integrity test is the gamma-gamma, or backscatter gamma test, illustrated here. This test typically uses PVC pipes installed in the concrete, not steel. The device is a nuclear density meter that must be calibrated frequently. It measures density in the concrete to about 4 inches from the edge of the tube. Newer devices can reportedly measure density to about twelve inches from the tube, but that characteristic is of little use if the tube is less than twelve inches from the edge of the shaft.

Gamma-gamma testing has the potential advantage of assessing the quality of the concrete outside of the rebar cage. However, a disadvantage of the device is that it does not “shoot” across the shaft as does a CSL device, so it does not test the entire cross-section, and it is sensitive to being placed too close to a longitudinal rebar. Otherwise, it is a very definitive test.

This is a gamma-gamma tool being lowered into a PVC access tube on a test shaft. After the probe is on the bottom of the tube, the probe is raised at a constant rate while gamma rays are emitted from the radioactive source. Logging consists of measuring the rate at which photons are detected by the detector. Probe characteristics vary between manufacturers, and each probe must be calibrated to establish the relationship between gamma ray counts and concrete density.



Personnel qualification requirements and reporting of the results from Thermal Integrity Testing will be similar to those for CSL testing.

Thermal Integrity Testing

- Measures the concrete temperature generated during the curing of the shaft concrete to assess the quality of the completed drilled shaft
- Develops plots of concrete temperature distribution.
- Can detect anomalies both inside and outside reinforcement cage
- Can assess cage alignment, reduced concrete coverage and bulges
- Test uses same type of tubes as CSL (steel or PVC)
- Tubes are not filled with water during the test
- Currently no ASTM standard specification for Thermal Integrity Testing
- Testing typically within 2-10 days after shaft completing depending on shaft diameter and concrete mix design.

Integrity Test Results

"Anomalies" – unusual patterns, voids or soft spots in the concrete.

Anomalies may be structural defects that require repair if they are confirmed with other supporting data (including inspection records and documentation) and after evaluation by the Engineer of Record.

There is a difference between an "anomaly" and a "defect". Anomalies are typically any deviation from what would normally be expected in the integrity test record. It may or may not turn out to be a "defect". A "defect", as defined here, is a structural condition in the shaft (usually an area of no concrete or very poor quality concrete) that will prevent the shaft from functioning as designed. Often, the magnitude and extent of anomalies detected by integrity testing need to be further defined so the Structural and Geotechnical Engineers can decide whether or not the condition is significant enough to require repair. Not all anomalies require any repair work or even any further investigation.

Integrity Test Results

If an anomaly is detected, the Engineer will determine course of action which may include:

- Additional CSL testing or tomography
- Excavation around shaft to expose defect
- Core drilling
- Down-hole cameras

Whatever the course of action is, the Engineer will want to review all of the shaft construction records to try and determine what caused the problem.

If an anomaly is detected that warrants further investigation (i.e., possible defect) the Engineer will consult with the Inspector regarding all aspects of shaft construction to determine what could have happened at the depth of the anomaly. This is a very important decision in that if, upon further investigation, there is no shaft defect found requiring repair, ODOT is responsible for paying the investigation costs along with additional compensation to the contractor for delaying drilled shaft construction due to the additional investigation work.

Section 00512.48

(c) Additional Testing and Investigation – Conduct additional testing or investigation necessary to identify the location, extent and condition of possible shaft defects if requested by the Engineer. Additional testing and investigation may include, but is not limited to, additional CSL testing, excavation work or core drilling.

Concrete Coring

- Number of holes, locations and depths determined by Engineer
- Log the boring like a regular borehole
- Take photos
- Record any driller comments on concrete quality

ODOT MATERIALS & INSPECTION

If core drilling is necessary the following procedures should be followed:

The foundation or bridge designer should plan the number, location and depth of all core holes based on the CSL test results and inspection reports. Core in the area(s) where the CSL results indicate possible defects. Do not let the contractor select core hole numbers, locations and depths. Core at least 3″ away from any rebar if possible and do not core through any steel reinforcement without the clear, expressed approval of the structural designer.

Carefully log all core holes, closely measuring depths, rate of advancement, any sudden drops in drill steel (indicating voids), percent recovery, concrete quality, breaks, fractures, inclusions and anything that does not indicate solid, good quality concrete. Take photos of the core recovery. Keep notes of any driller remarks regarding the nature and quality of the shaft concrete.

Core samples are then typically submitted to the Materials lab for concrete testing.

Coring can bypass serious defects if they are not carefully located and even still may miss defects. However, very careful coring is sometimes an effective way to investigate whether there is a soft base in the drilled shaft. In some cases the core holes may also be used for grouting and repair of shaft defects.

The core holes must be carefully filled with grout after completion and only with the approval of the engineer.

Concrete Coring

Section 00512.48

Additional Testing and Investigation – (continued)

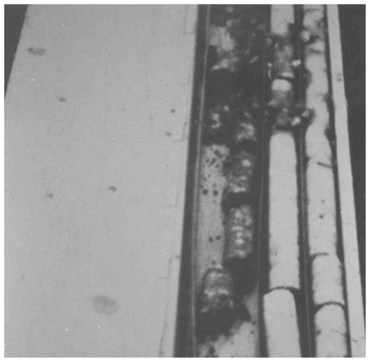
If requested by the Engineer, drill a core hole in any questionable quality shaft to explore the shaft condition. The number, location and depths of the core holes will be determined by the Engineer. Submit the method and equipment used to drill and remove cores from the shaft to the Engineer for review and approval prior to drilling. Use a coring method that provides complete core recovery and minimizes abrasion and erosion of the core. If a defect is confirmed, as determined by the Engineer, all investigation costs associated with identifying the defect will be at no additional cost to the Agency and no extension of the Project completion date will be granted, regardless of whether the identified defect is repaired or not.

If no defect is identified in the investigation work, and the CSL tubes were satisfactorily installed according to ASTM D 6760 and accepted, the Agency will pay for all coring and excavation costs associated with the additional investigation and grant an appropriate time extension, if required, according to Section 00190 and Section 00195. If it is determined by the Engineer that the CSL tubes were not installed properly thus invalidating the CSL test results, all coring, excavation, and other investigation and evaluation costs will be at no additional cost to the Agency and no extension of the Project completion date will be granted.

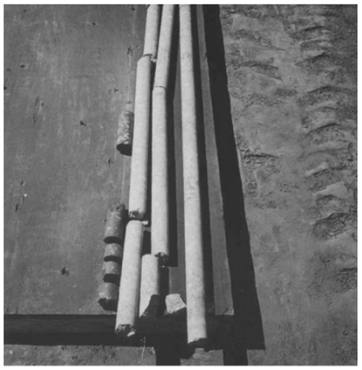
Fill all core holes with grout only after the evaluation process is completed and the shaft is accepted and approved.

Concrete Coring

- Coring is not always definitive in ruling out defects.
- Defects can be missed by the coring tool.



Not Good



Acceptable

These photos show the cores from two drilled shafts. The core on the right was from a shaft that was apparently acceptable (a companion core in the same shaft also showed no signs of defects, so the state DOT accepted the shaft). The core on the left was taken from a shaft that was constructed on a batter, with temporary casing, and the temporary casing was withdrawn as the concrete was beginning to set, compromising the quality of the concrete. The Contractor was required to excavate about 15 feet of soil from around the shaft and to reform and repair the top of the shaft. So, in these cases, coring alone was deemed successful.

A disadvantage of coring relative to integrity tests is that it consumes more time and requires the core hole to be carefully filled with grout. It may also be difficult to position a coring rig atop the shaft, whereas minimal equipment is needed atop the shaft in conducting integrity tests.

Shaft Repairs

Section 512.48(d) "Drilled Shaft Repair" and

Section 512.40(b) "Drilled Shaft Repair Plans"

- Repair plan submitted by Contractor and approved by the Engineer
- Do not begin repair operations before remedial procedures or designs are approved.

00512.48 (d) Drilled Shaft Repair – Repair all defects and rejected shafts according to 00512.40(b). Perform additional CSL testing, or other investigation required, as directed by the Engineer, to confirm the quality of the completed shaft repair work at no additional cost to the Agency with no time extension granted.

For temporary casing not extracted from the shaft excavation, submit a repair plan or a structural evaluation to the Engineer for approval according to 00512.40. If caving occurs during concrete placement submit a repair plan to the Engineer for approval.

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Shaft Repairs

Possible Solutions:

- Excavate upper portion of shaft and repair defect area.
- Clean out defect area with high pressure water jets and fill with non-shrink grout.
- Replace Shaft
- Add additional piling or other deep foundation elements around perimeter of shaft.

00512.40 Submittals

(b) Drilled Shaft Repair Plans – For any shaft determined to be unacceptable, submit a repair plan to the Engineer for approval. Furnish all materials and work, including engineering analysis and design, needed to correct unacceptable drilled shafts, at no additional cost to the Agency. Do not begin repair operations before remedial procedures or designs are approved. Any modifications to the dimensions or material of the drilled shafts shown on the plans that are proposed in the repair plan will require stamped calculations and working drawings according to 00150.35.

Shaft Repairs

Excavate upper portion of shaft and repair defect area.

This is an ODOT project where a defect was discovered from CSL testing in the upper portion of the shaft. In this case it was possible to excavate the soil around the upper part of the shaft and replaced it with low-strength concrete. A shaft repair like this can greatly affect the lateral seismic response a bridge and therefore has to be carefully reviewed and approved by the Engineer of Record.

While the previous slides may suggest that defects in drilled shafts are numerous, a defective shaft should be the exception rather than the rule. If the contractor follows good practices and procedures drilled shafts should look like this. This is a 70-foot long shaft constructed under mineral drilling slurry, load tested to geotechnical failure and then exhumed for observation. The shaft was almost perfectly cylindrical, and no concrete contamination could be observed.

Load Tests

Typically there are three types of load tests conducted on drilled shafts:

- Axial (downward) ASTM D 1143
- Lateral (sideways) ASTM D 3966
- Uplift (upwards) ASTM 3689

Axial load tests- tests to determine if the shaft can carry the downward load imposed without settling.

Lateral load tests- these are tests that test the shafts resistance to lateral (sideways) forces.

Uplift tests- these tests are the opposite of axial, in that rather than push downward on the shaft, it is pulled upward to determine its resistance to being “pulled out”.

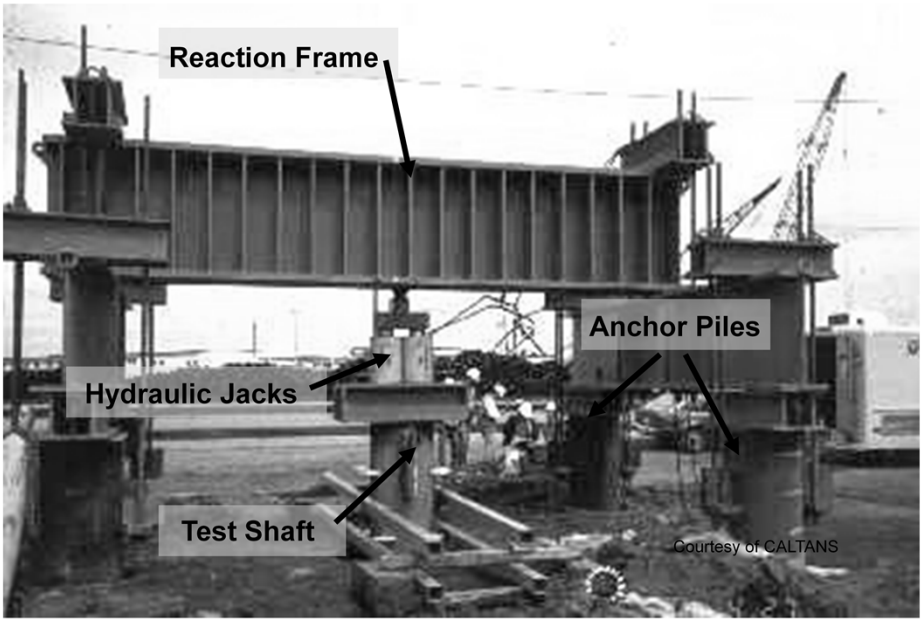
Axial Load Tests

There are three types of Axial Load tests:

- Conventional methods
  (reaction frame and reaction shafts)
- Osterberg load cell(s)
- Statnamic loading device

Full scale axial load tests are rarely performed in ODOT but there are some from time to time and there may be more in the future. Axial (downward) tests using the Osterberg Load Cell (O-Cell) are the most common. This test measures both uplift and downward (tip) capacity. The O-Cell method is getting to be more common due to its lower cost verses a conventional full scale test.

Conventional Method
(Reaction Frame and Reaction Piles)

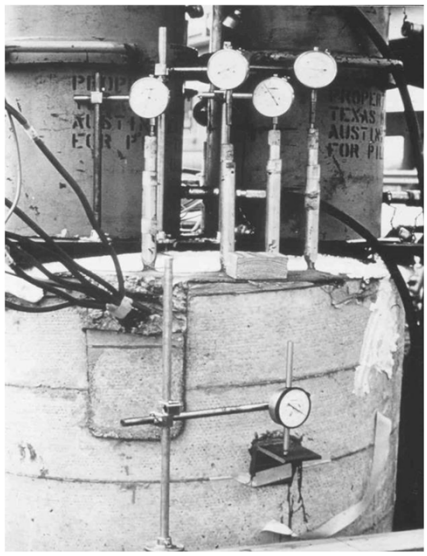


In a conventional test, reaction (anchor) shafts are installed on either side of the test shaft (two or four can be used). The reaction shafts should each have approximately the same capacity in uplift as the test shaft has in compression (if two are used), to assure a factor of safety of about two to preclude anchor shaft failure. The anchor shafts should normally be installed first. Hydraulic jacks are placed on top of the test shaft, usually on a steel plate that is carefully leveled. Electronic load cells are also frequently placed above or below the jacks in order to obtain an accurate measure of the load. A reaction frame spans the anchor shafts, as shown.

Potential disadvantages of this method are that it is relatively expensive compared to the other methods (perhaps twice as expensive, excluding the cost of the test shaft) and the capacity is limited because of the use of the reaction frame.

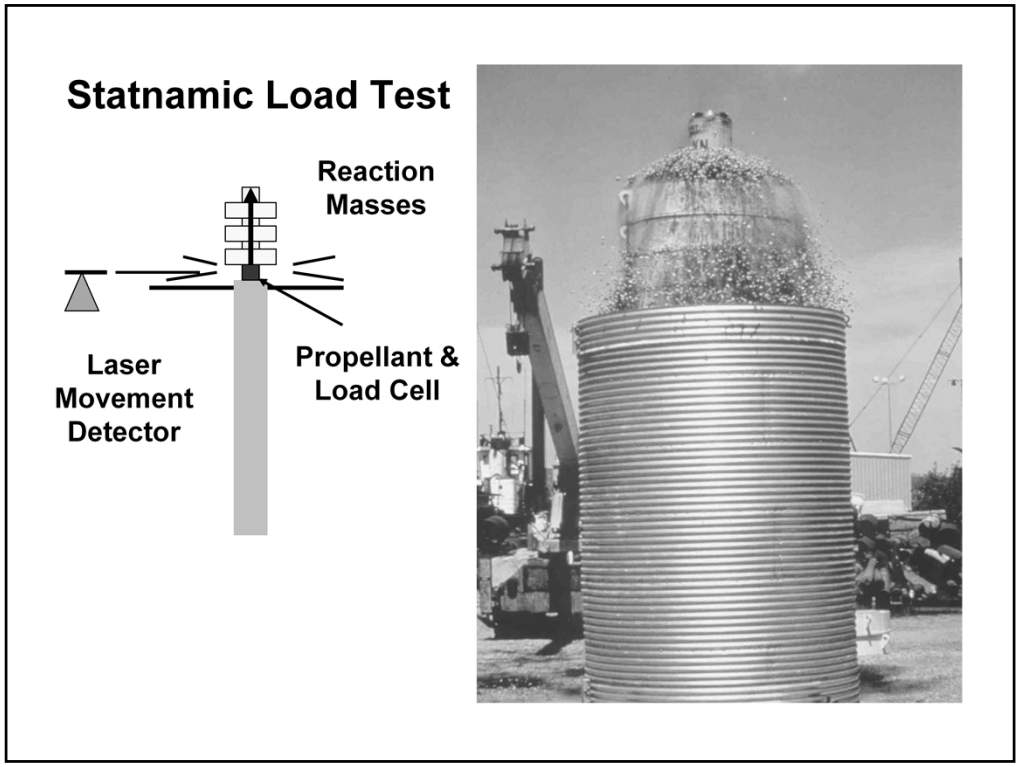
The conventional method can also be used to conduct uplift, or “pullout,” tests.

Conventional Method
(Reaction Frame and Reaction Shafts)

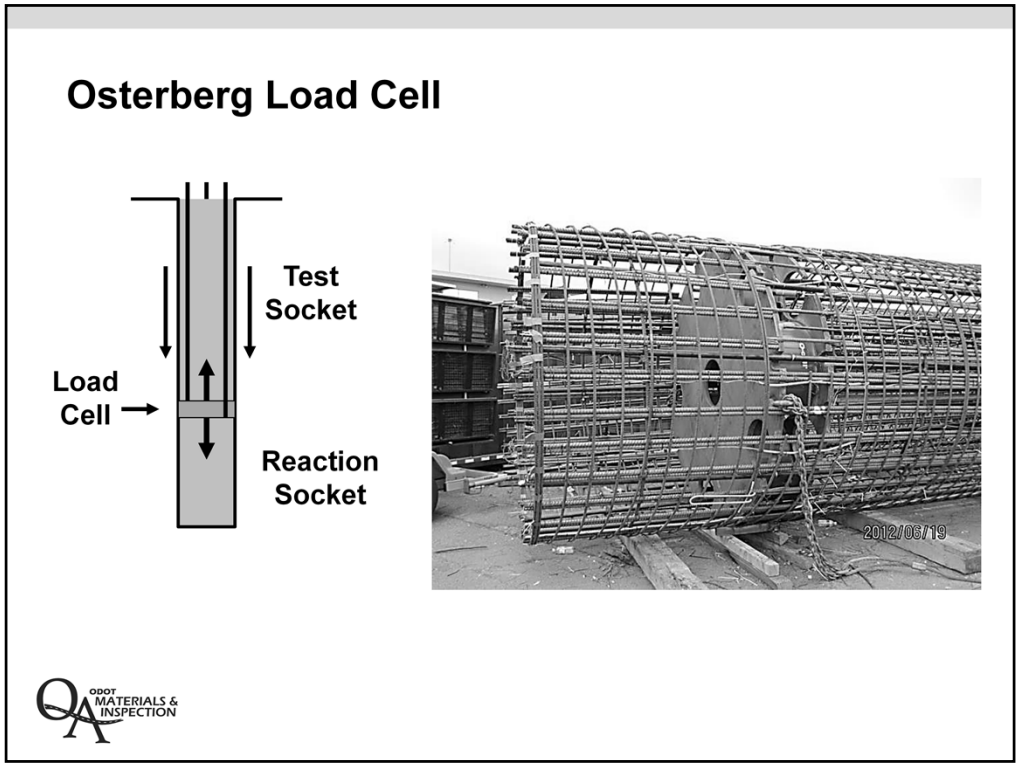


These are some photos of the set-up for axial load tests on drilled shafts. On the left is a jack with a pressure gauge calibrated to load (dark gray object), an electronic load cell (silver object), and settlement gauges, in this case mechanical dial gauges. LVDT's or DCVT's can be used in place of dial gauges conveniently if a computer at the field site acquires data. Four settlement gauges are used, one at each corner of a thick steel loading plate affixed to the head of the drilled shaft. Reference beams that are supported on the ground at points at least 10 feet, clear, from the test and reaction shafts support the settlement gauges. These steel reference beams are shaded from the sun by means of a tarpaulin in order to minimize thermal movements in the reference beams. Two independent means, the electronic load cell and the jack pressure, read the load on the jack. A second, independent method for reading settlement is also a good idea in case the zero is lost on the settlement gauges (very large settlements beyond the range of the settlement gauges, blunder by field crew in hitting reference beams, etc.) This is often accomplished by making optical level readings on a scale affixed to the shaft head. Some mention of desired accuracy in the load and settlement readings might be inserted here.

On the right we see the tops of several telltales. These are unstrained rods that are anchored at various depths within the test shaft. Differences in compression between the top of the shaft and the anchor points are read by the gauges (0.0001 inch dial gauges in this photo). These differences are converted into axial strains and then to stresses and finally to load in order to measure the distribution of load along the shaft. The keys to good telltale readings are rods that do not bind inside their sheaths and accurate estimates of concrete modulus (to convert strain to stress).

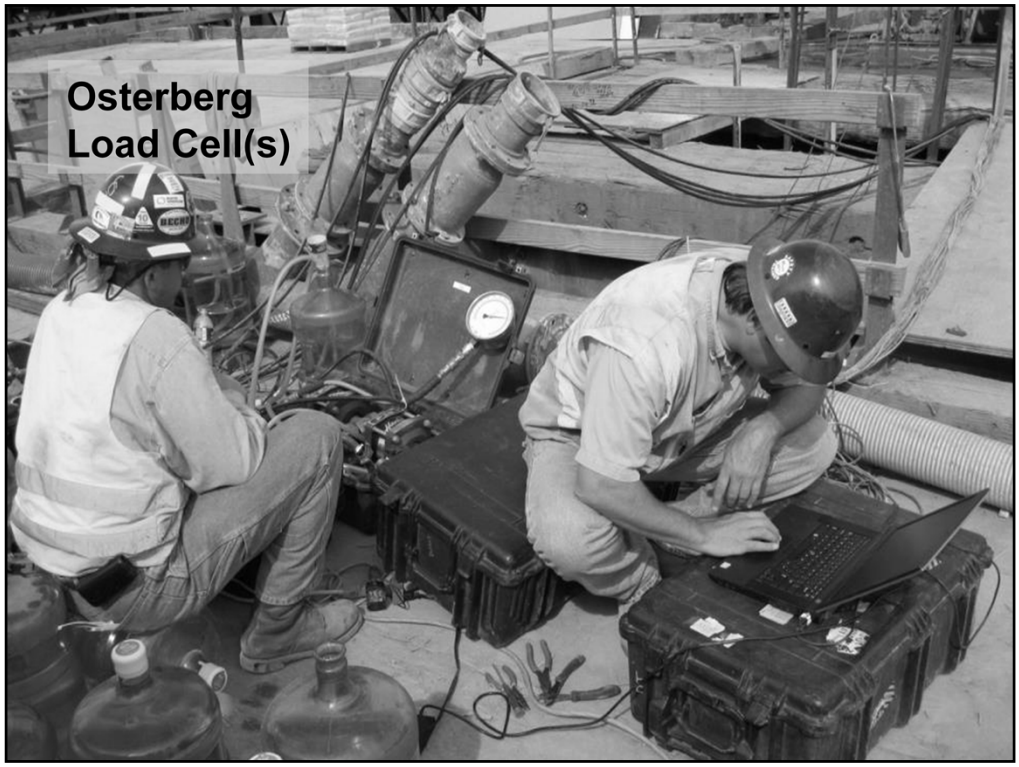


An alternate way of testing drilled shafts is the Statnamic® test method. An advantage of this method relative to the Osterberg Cell method is that it can be used to test shafts that are not initially planned for testing. (In the Osterberg Cell method the cell must be cast into the shaft at the time of construction.) The principle of operation is shown on the left. Heavy masses on top of the shaft are accelerated upward by a propellant. This produces a force against the masses equal to the mass of the accelerated masses time the magnitude of the acceleration and an equal and opposite force on the top of the shaft. The force is active for perhaps half a second (500 milli sec), with a rise time of 100 - 200 milli sec. This rise time is long enough to produce a stress wave in the shaft that is longer than the shaft itself (if the shaft is, say 65 feet long or shorter), in which case the shaft can be treated for data reduction purposes as a rigid body. On the right is a photo of a Statnamic test being performed. Gravel, contained within a steel sheath, is usually placed around the masses in order to cushion their impact when they fall back onto the top of the shaft. Newer support devices have recently been deployed with guides that contain the reaction masses laterally as they move upward and “catch” them as the fall back to the head of the shaft. This does away with the need for gravel and speeds up the testing process. Statnamic tests can be run to almost any magnitude of load from a few tons to 3600 tons (1999), by changing components in the system.



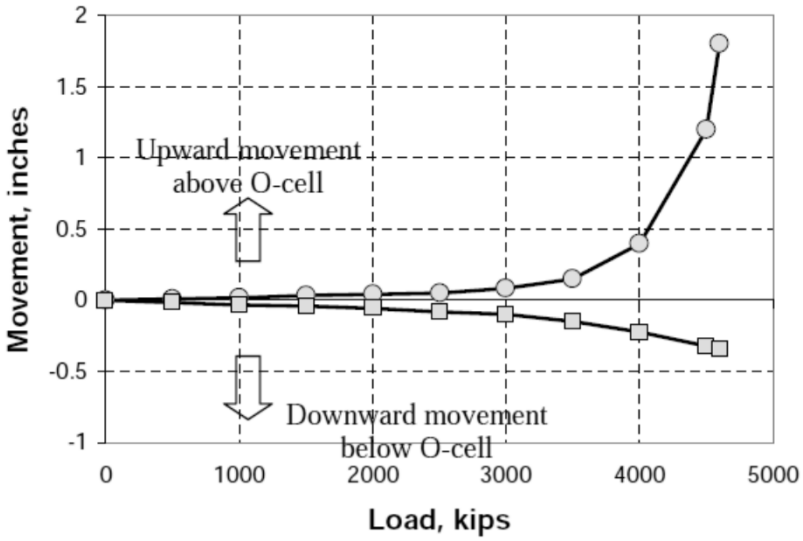
This slide is given to indicate the principle of the operation of the Osterberg Load Cell. Five 3000-ton cells (photo on right) are used here to test a 10-ft diameter shaft drilled into soft to moderately hard rock. There are 2-inch thick steel plates attached to the tops and bottoms of the load cells. In this case the objective of the test was to find the ultimate side shearing resistance in the soft rock. Since the load cells push both up and down with the same amount of force, calculations are made to find the best location to place the load cells in the shaft so that there are equal amounts of resistance (in either skin friction or end bearing) above and below the location of the load cells. That way the maximum amount of resistance can be obtained from the test.

Other configurations can be used to test end bearing only or to test both end bearing and side resistance using multiple levels of cells.

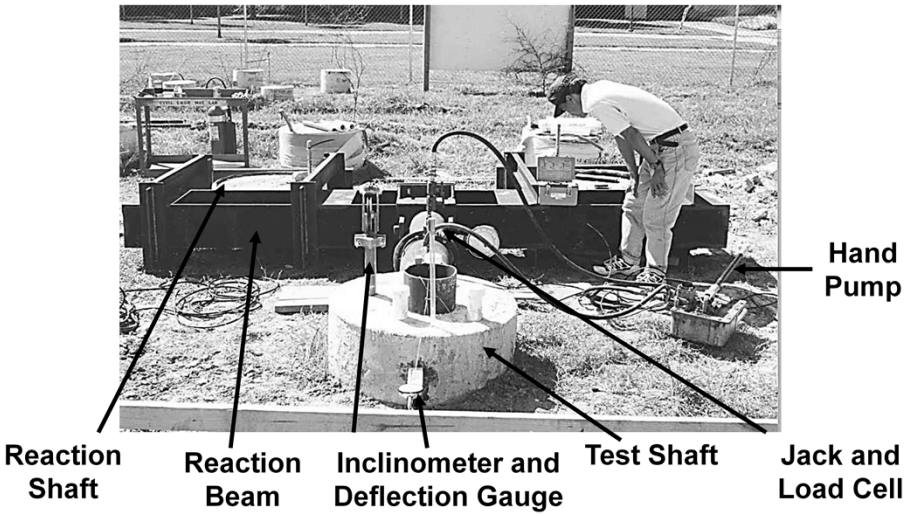


Technician running an Osterberg Load Test (Sandy River, OR).

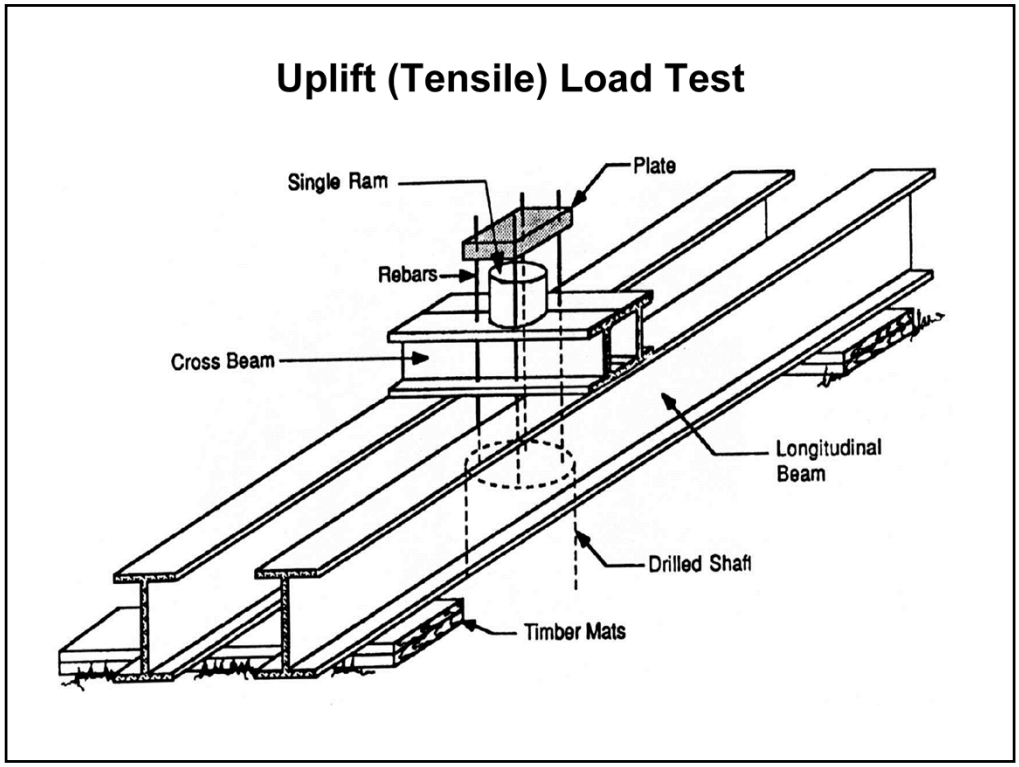
The graph shows a plot of the load verses deflection of the shaft segments above and below the O-cell. In this case the O-cell is on the bottom of the shaft so the test is measuring both tip resistance (downward direction) and side resistance (upward direction). The lower curve (bending downward) is a plot of the base (tip) resistance.



Lateral Load Test



This is a photo of a typical, simple arrangement for loading a drilled shaft laterally. Two companion shafts are used to support the load from the reaction beam. The test shaft is pushed away from the reaction shafts, not pulled toward them (which might produce excessive stress overlaps in the soil). The load is applied as a shear at the ground level and is measured with an electronic load cell. Both the lateral deflections at the level of the applied load and the slope of the shaft (at the head and along the shaft) are measured.



The conventional method can also be used to conduct uplift, or “pullout,” tests using a configuration similar to that shown for the axial load test. Conventional pullout tests are often less expensive than conventional compression tests because the reaction beam can often be placed on mats or cribbing, eliminating the need for expensive reaction shafts.

If production shafts are to be subjected to substantial uplift loading during their design lives (e.g., because of overturning moments applied to the structure through seismic events or extreme winds, foundations at the anchorage end of permanent cantilevers), it is appropriate to perform uplift tests. An arrangement for the performance of a conventional uplift test of a drilled shaft is shown above. The key feature of the arrangement is that some of the longitudinal rebars, that are embedded full length in the test shaft, extend upward to a point well above the head of the test shaft. It is helpful if these extended rebars are made of high-strength steel.

Drilled Shaft Inspection Report

- Required to be filled out by the Contractor (512.40c)
- Available on ODOT Construction Section Web Page (Form 734-2598)
- Submit the report within 21 calendar days after the completion and acceptance of each shaft

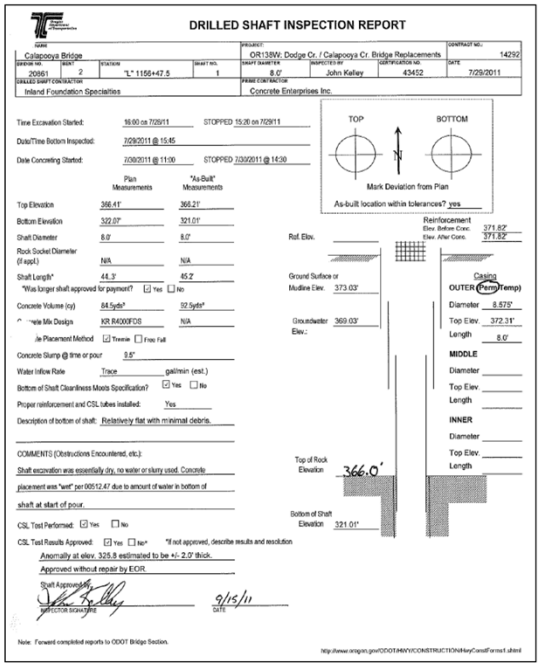
00512.40 Submittals – Provide the following submittals to the Agency for review and approval:

(c) Drilled Shaft Inspection Reports – Provide the Engineer with a completed Drilled Shaft Inspection Report for each drilled shaft, detailing the actual location, alignment, elevations, dimensions, and quantities of the shafts.

Submit the report within 21 calendar days after the completion and acceptance of each shaft. A Drilled Shaft Inspection Report form is available from the Engineer.

Drilled Shaft Inspection Report

Example of completed report



DRILLED SHAFT INSPECTION REPORT

NAME				PROJECT:			CONTRACT NO.
Calapooya Bridge				OR138W: Dodge Cr. / Calapooya Cr. Bridge Replacements			14292
BRIDGE NO.	BENT	STATION	SHAFT NO.	SHAFT DIAMETER	INSPECTED BY	CERTIFICATION NO.	DATE
20861	2	"L" 1156+47.5	1	8.0'	John Kelley	43452	7/29/2011
DRILLED SHAFT CONTRACTOR				PRIME CONTRACTOR			
Inland Foundation Specialties				Concrete Enterprises Inc.			

Time Excavation Started: 16:00 on 7/28/11 STOPPED 15:20 on 7/29/11

Date/Time Bottom Inspected: 7/29/2011 @ 15:45

Date Concreting Started: 7/30/2011 @ 11:00 STOPPED 7/30/2011 @ 14:30

	Plan Measurements	"As-Built" Measurements
Top Elevation	366.41'	366.21'
Bottom Elevation	322.07'	321.01'
Shaft Diameter	8.0'	8.0'
Rock Socket Diameter (if appl.)	N/A	N/A
Shaft Length*	44.3'	45.2'
*Was longer shaft approved for payment? ☑ Yes ☐ No		
Concrete Volume (cy)	84.5yds³	92.5yds³
Concrete Mix Design	KR R4000FDS	N/A
Concrete Placement Method	☑ Tremie ☐ Free Fall	
Concrete Slump @ time or pour	9.5"	
Water Inflow Rate	Trace gal/min (est.)	
Bottom of Shaft Cleanliness Meets Specification?	☑ Yes ☐ No	
Proper reinforcement and CSL tubes installed:	Yes	
Description of bottom of shaft:	Relatively flat with minimal debris.	

COMMENTS (Obstructions Encountered, etc.):
Shaft excavation was essentially dry, no water or slurry used. Concrete placement was "wet" per 00512.47 due to amount of water in bottom of shaft at start of pour.

CSL Test Performed: ☑ Yes ☐ No

CSL Test Results Approved: ☑ Yes ☐ No* *If not approved, describe results and resolution
Anomaly at elev. 325.8 estimated to be +/- 2.0' thick.
Approved without repair by EOR.

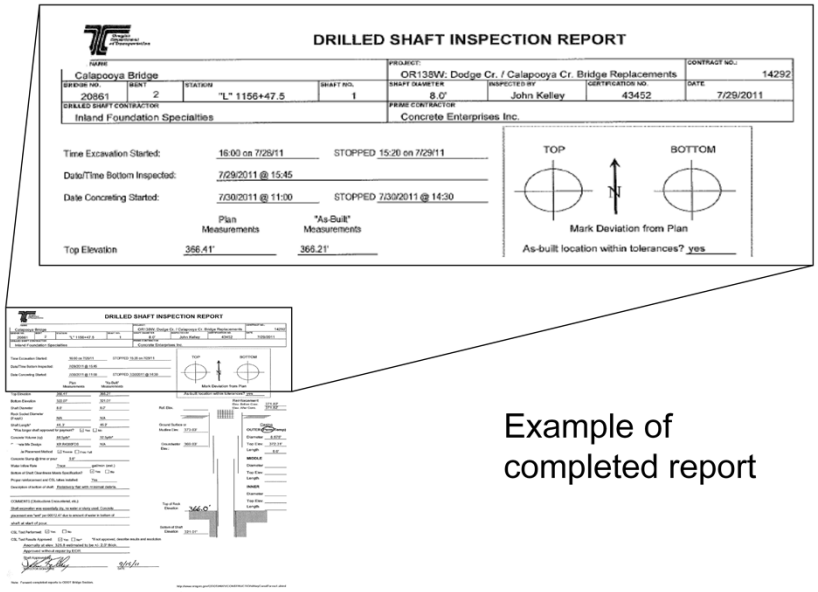
Shaft Approved by: John Kelley 9/15/11
INSPECTOR SIGNATURE DATE

Note: Forward completed reports to ODOT Bridge Section.

http://www.oregon.gov/ODOT/HWY/CONSTRUCTION/HwyConstForms1.shtml

Example of a completed Drilled Shaft Inspection Report

Drilled Shaft Inspection Report



DRILLED SHAFT INSPECTION REPORT

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Date Concreting Started: 7/30/2011 @ 11:00 STOPPED 7/30/2011 @ 14:30

	Plan Measurements	"As-Built" Measurements
Top Elevation	366.41'	366.21'

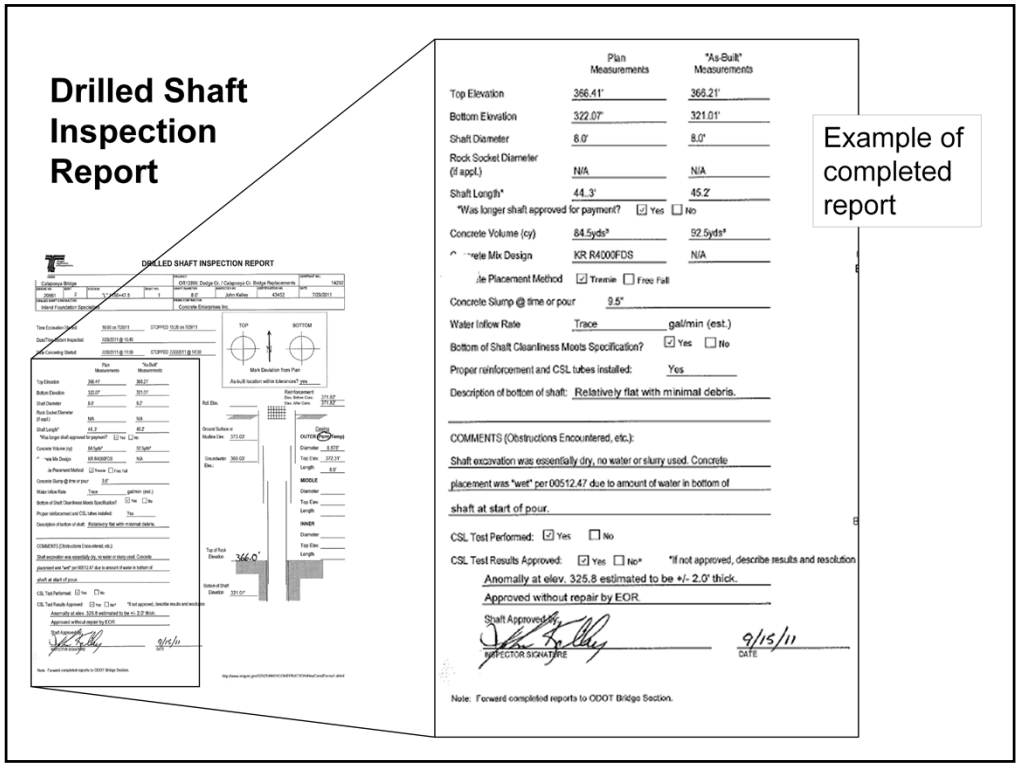
TOP BOTTOM N

Mark Deviation from Plan

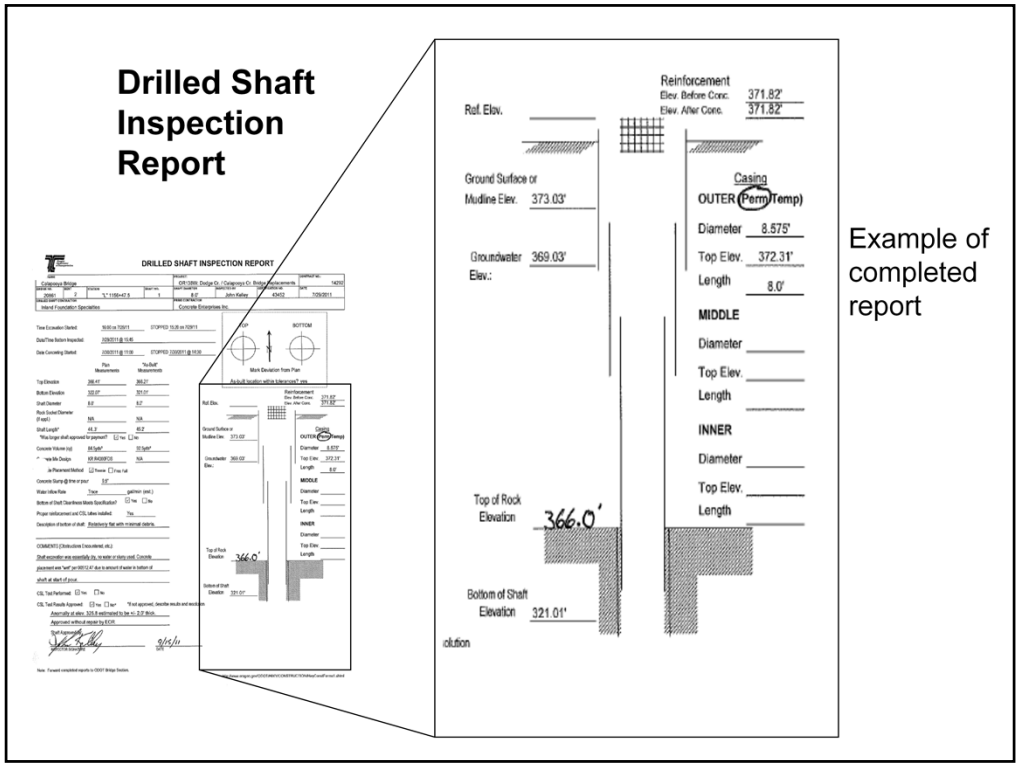
As-built location within tolerances? yes

Example of completed report

Example of a completed Drilled Shaft Inspection Report



Example of a completed Drilled Shaft Inspection Report



Example of a completed Drilled Shaft Inspection Report

ODOT Drilled Shaft Inspection Checklist

Post Installation

- ☐ Yes ☐ No ☐ NA 40. Is all casing removed to the proper elevations in accordance with 00512.47(e)?
- ☐ Yes ☐ No ☐ NA 41. Is the concrete being cured in accordance with Section 00540.51?
- ☐ Yes ☐ No ☐ NA 42. Has all Crosshole Sonic Log (CSL) Testing been completed in accordance with Section 00512.48?
- ☐ Yes ☐ No ☐ NA 43. Is the shaft within the allowable construction tolerances (00512.42)?
- ☐ Yes ☐ No ☐ NA 44. Has the Contractor completed the Drilled Shaft Inspection Report (00512.40(c))?
- ☐ Yes ☐ No ☐ NA 45. Has the Inspector completed the Drilled Shaft Inspection Report (00512.40(c))?

ODOT MATERIALS & INSPECTION

40. Is all casing removed to the proper elevation in accordance with 00512.47(e)?

- Remove all temporary casing in accordance with the specifications
- **00512.47(e) Casing Removal** – Remove the tops of permanent casing to the top of the drilled shaft or the finished groundline, whichever is lower, unless otherwise shown or directed. Remove the tops of permanent casing for shafts constructed in a permanent body of water to the low water elevation, unless otherwise shown or directed.

All temporary casing should be removed. If it cannot be removed for some reason the engineer must be notified. Permanent casing should be cutoff to the lengths shown on the plans.

00512.47 Concrete -

(e) Casing Removal - Remove all temporary casing during or after completion of concrete placement. Do not start temporary casing removal until the level of fresh concrete within the casing has reached a depth of at least 10 feet or the level necessary to adequately counteract the external hydrostatic pressure head. As the temporary casing is withdrawn, maintain a minimum 5 feet head of concrete above the bottom of the casing. A slight downward movement of the casing while exerting downward pressure, or hammering or vibrating the casing will be allowed to facilitate extraction. Extract the casing so that concrete is cast directly against the surrounding in-situ material. Check the elevation of the top of the reinforcing cage before and after temporary casing extraction for conformance with the construction tolerance criteria of 00512.42. Casing that cannot be extracted during, or immediately after, the concrete placement operation may be cause for rejection of the shaft.

Remove the tops of permanent casing to the top of the drilled shaft or the finished groundline, whichever is lower, unless otherwise shown or directed. Remove the tops of permanent casing for shafts constructed in a permanent body of water to the low water elevation, unless otherwise shown or directed.

41. Is the concrete being cured in accordance with 00540.51?

00540.52 Curing Concrete

- Cure cast-in-place concrete with water. Begin curing as soon after placement as possible without damaging the freshly placed concrete
- Continue curing for 7 calendar days after placement.

42. Has all crosshole sonic log testing been completed in accordance with specification 00512.48?

00512.48 Drilled Shaft Testing and Acceptance

- The Contractor is typically responsible for performing the integrity tests and submitting results in the form of a report.
- The number of CSL tests to perform are listed in the bid items for each structure.
- Fill CSL tubes with grout only after the shaft CSL test results have been reviewed and the shaft accepted by the Engineer.

Check that:

- The CSL testing was conducted after the minimum 3-day curing time wait period unless otherwise approved.
- The tubes were full of water from the time the pour was completed to the time of the test. This is to make sure the tubes are adequately bonded to the concrete.
- The approved personnel conducted the test.
- All CSL tube combinations were tested.
- The required reports were submitted for each test.
- The CSL tubes are filled with grout **ONLY AFTER** the CSL results have been reviewed by the Engineer of Record and the shaft is approved.

43. Is the shaft within the allowable construction tolerances (00512.42)?

- Horizontal position
  (at the Plan Elevation of the Top of Shaft)
- Top elevation of shaft concrete
- Vertical alignment in soil
- Vertical alignment in rock
- Top of steel reinforcement

00512.42 Construction Tolerances – Excavate drilled shafts as accurately as possible at the locations shown and within the specified tolerances listed below. Determine the drilled shaft dimensions and alignment with approved methods. The following construction tolerances apply to drilled shafts unless otherwise stated:

Horizontal Position (At the Plan Elevation of the Top of Shaft):

- **Shaft Diameter Less Than or Equal to 6 Feet** – 3-inch horizontal tolerance from the location shown.
- **Shaft Diameter Greater Than 6 Feet** – 6-inch horizontal tolerance from the location shown.

Top Elevation of Shaft Concrete:

- **Top Elevation Above Water** – Minus 3 inches to plus 1 inch from the plan top of shaft elevation.
- **Top Elevation Under Water** – Minus 3 inches to plus 6 inches from the plan top of shaft elevation.

Vertical Alignment in Soil – May not vary from the plan alignment by more than 1.5% of the shaft length.

Vertical Alignment in Rock – May not vary from the plan alignment by more than 2% of the shaft length.

Top of Steel Reinforcement – Plus or minus 6 inches from the plan top of steel reinforcement elevation.

44. Has Contractor completed the Drilled Shaft Inspection Report in accordance with 00512.40(c)?

45. Has the Inspector completed the Drilled Shaft Inspection Report (00512.40(c))?

- The Drilled Shaft Inspection Report compiles all of the data recorded during the installation into one concise form for permanent records.
- Contains “As-built” shaft construction information

Section 00512.40

(c) Drilled Shaft Inspection Reports – Provide the Engineer with a completed Drilled Shaft Inspection Report for each drilled shaft, detailing the actual location, alignment, elevations, dimensions, and quantities of the shafts.

Submit the report within 21 calendar days after the completion and acceptance of each shaft. A Drilled Shaft Inspection Report form is available from the Engineer.

The contractor is also required to provide the Concrete Placement Logs and Volume Curves for each shaft:

(d) Concrete Placement Logs and Volume Curves – Measure and record all concrete placed into drilled shafts using standard ODOT forms designated for this purpose or other forms approved by the Engineer. Provide the Engineer with a completed Drilled Shaft Concrete Placement Log and Concrete Volume Curve Form for each drilled shaft within 24 hours after completion of shaft concrete placement.

Unit Review

- Describe when the contractor may proceed with subsequent shaft construction
- Verify if Contractor is in compliance with tolerance criteria
- Identify and describe various integrity and load tests
- Describe how to complete the Drilled Shaft Inspection Report

ODOT MATERIALS & INSPECTION