# CUY-90-14.90

## PID 77332/85531

# APPENDIX GE-08

## Drilled Shaft Testing

## (Contract Document)

State of Ohio
Department of Transportation
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**Innerbelt Bridge**
**Construction Contract Group 1 (CCG1)**

Revision Date: January 13, 2010

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**STATE OF OHIO**
**DEPARTMENT OF TRANSPORTATION**

**SPECIFICATION FOR**
**Crosshole Sonic Logging (CSL) Testing for Drilled Shafts**
**CUY-90-14.52 (PID 77332)**

**January 2010**



**Refer to the Specification for Crosshole Sonic Logging (CSL) Testing for Drilled Shafts for requirement on the installation of access tubes.**

**01 DESCRIPTION**: This work consists of evaluating the structural integrity of drilled shafts using the crosshole sonic logging (CSL) test method. The work also consists of furnishing and installing access tubes required to conduct the testing, and core drilling of concrete to confirm possible defects.

CSL testing measures the time it takes for an ultrasonic pulse to travel from a signal source in one access tube to a receiver in another access tube. In uniform, good quality concrete, the travel time between parallel tubes will be relatively constant and correspond to a reasonable signal velocity from the bottom to the top of the drilled shaft. In uniform, good quality concrete, CSL testing will also measure strong signal amplitude and energy readings. Long travel times, low signal amplitude, or low energy readings indicate the presence of anomalies that may consist of poor quality concrete, voids, honeycombs or soil intrusions. The signal may be completely lost by the receiver and CSL recording system for severe defects such as voids and soil intrusions.

**02 MATERIALS**: Furnish materials conforming to:

Portland cement ............................... 701.02
Chemical admixture......................... 705.12

Cement grout consists of a mixture of cement and water that provides a minimum 28-day compressive strength equal to, or greater than, the drilled shaft concrete. Determine the compressive strength of the cement grout according to ASTM C 39 or ASTM C 942. Admixtures which control bleed, improve flowability, reduce water content, and retard set may be used in the grout if accepted by the IQF (Independent Quality Firm). For grout, use water free from sewage, oil, acid, strong alkalis, vegetable matter, clay, and loam. Potable water is satisfactory for use in grout.

Furnish access tubes consisting of ASTM D 1785 Schedule 40 PVC pipe with a nominal diameter of 2.0 inches (50 mm). Access tubes shall have round, regular inside surfaces free from defects and obstructions, including all pipe joints, in order to permit the free, unobstructed passage of the probes. Access tubes shall be free from contaminants to ensure a good bond to the concrete.

Submit the grout mix and the selected pipe for the access tubes with the Drilled Shaft Installation Plan for the IQF's acceptance. Also include for the IQF's acceptance the proposed method for joining the pipe and for attaching the pipe to the reinforcing steel cage.

**03 NDT CONSULTANT**: Retain an experienced Nondestructive Testing (NDT) consultant to perform or supervise the CSL testing. The NDT consultant shall have at least two years experience in CSL testing. Submit to the IQF for acceptance a resume of the credentials of the proposed NDT consultant at least 14 Calendar Days before constructing the drilled shafts.

**04 INSTALLATION OF ACCESS TUBES**: Install access tubes in all Contract drilled shafts to permit access for the CSL test equipment. Use Table No. 04-1 to determine the number of access tubes per shaft and the tube spacing. If the shaft diameter varies along the length of the shaft, use the largest diameter to determine the number of access tubes.

**TABLE 04-1**

| Shaft Diameter | | Number | Tube Spacing |
|---|---|---|---|
| (feet) | (mm) | of Tubes | (degrees) |
| 4.0 to 5.0 | 1200 to 1530 | 4 | 90 |
| 5.5 to 7.5 | 1670 to 2280 | 6 | 60 |
| 8.0 to 9.5 | 2440 to 2900 | 8 | 45 |
| 10.0 to 12.0 | 3050 to 3660 | 10 | 36 |

Provide watertight joints, a watertight cap on the bottom, and a removable cap at the top of the access tubes. Do not cover joints with tape or other wrapping material. Attach the tubes to the interior of the reinforcing steel cage so that the tubes are parallel and evenly spaced around the perimeter of the reinforcing steel cage. Provide a minimum concrete cover of 3 inches (75 mm). Install the access tubes so that the bottom of the tube is 6 inches (150 mm) or less from the bottom of the drilled shaft but does not touch the bottom of the shaft. Wire-tie or secure the access tubes to the reinforcing steel cage every 3 feet (1 meter). Extend the top of the access tubes at least 3 feet (1meter) above the top of the drilled shaft. If the top of the drilled shaft is below the surface, extend the top of the access tubes at least 2 feet (0.6 meter) above the ground surface. Ensure that the access tubes do not move during placement of the cage and concrete.

Within 4 hours of placing the reinforcing steel cage but before placing the concrete, fill the access tubes with clean water and recap the tubes. After placing the concrete, exercise care when removing the caps from the access tubes so as not to apply excess torque, hammering, or other stresses which could break the bond between the tubes and the concrete. Label each access tube with a unique identifier at the top of the tube.

**05 INSTALLATION OF ADDITIONAL ACCESS TUBES FOR DEMONSTRATION DRILLED SHAFT(S):** Refer to the Specifications for Gamma-Gamma Testing for Drilled Shafts for the requirements on the installation of additional access tubes for demonstration drilled shaft(s).

**056 TEST PROCEDURE**: Before CSL testing, supply the IQF and NDT Consultant with a record of the length, top elevation, bottom elevation, and date of concrete placement for all drilled shafts. Perform CSL tests in accordance with ASTM D 6760 except as modified by this specification. Perform CSL tests on all drilled shafts including the demonstration drilled shafts. Perform the CSL test after the concrete develops sufficient strength and before debonding of access tubes from the surrounding concrete. The IQF may direct a longer minimum time if the drilled shaft concrete contains a retarding admixture or uses a mix design that results in a longer setting time for the drilled shaft concrete.

For shafts with 4 or 6 access tubes, obtain readings between all pairs of tubes. For shafts with 8 or 10 access tubes, obtain readings between adjacent pairs of access tube around the perimeter, between pairs of access tubes across the diameter of the shaft, and between pairs of access tubes that are spaced at two times the spacing shown in Table 04-1 (See Figure 05-1 for a diagram). Obtain readings at depth intervals of 0.2 feet (50 mm) or less. If possible defects are detected, obtain additional readings to confirm the initial readings at no additional cost to the Department. Notify the IQF and the Engineer of possible defects within 24 hours of testing.

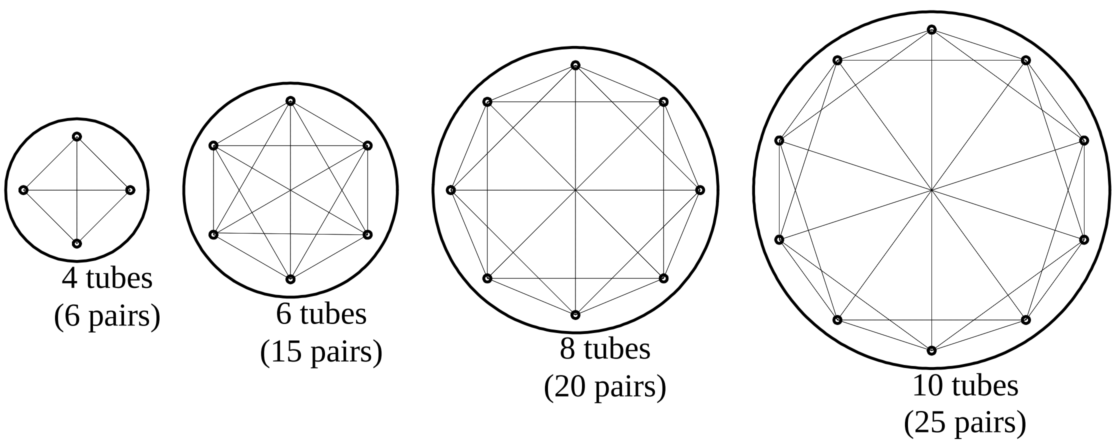


**FIGURE 05-1**

**067 TEST REPORT**: Present the CSL test results in a written report. Supply the IQF with two copies of the report within seven Calendar Days after completion of the CSL testing. The IQF may require separate reports for each substructure depending on the number of drilled shafts or the length of the drilled shaft construction schedule. If separate reports for each substructure are required by the IQF, supply the report within seven Calendar Days after completion of testing at that given substructure.

In addition to the report requirements in ASTM D 6760, indicate all possible defects on the CSL logs and include a summary of all possible defects detected during the CSL testing. The summary shall indicate for each possible defect:

A. the drilled shaft identification,

B. test date,

C. number of days between concrete placement and CSL testing,

D. access tube pairs tested,

E. depth below top of shaft,

F. percent wave speed reduction, and

G. an evaluation of the defect.

**078 EVALUATION OF TEST RESULTS**: The IQF will evaluate the CSL test results and determine if the drilled shaft construction is acceptable. If the CSL test results indicate possible defects in the drilled shaft, the IQF or the Engineer may require coring of the drilled shaft to obtain samples in the area of the possible defect, or excavation of the drilled shaft to examine the condition of the concrete. The IQF or the Engineer may require testing of the core samples. The IQF and the Engineer will consider the CSL test results, the condition of the concrete as shown by core samples, results of testing on the core samples, and other information when determining the acceptability of the drilled shaft. The DBT shall not proceed with construction of substructures or structures above a drilled shaft until the IQF and the Engineer have accepted the drilled shaft.

If examination of the drilled shaft concrete confirms the presence of a defect in the drilled shaft, then the Department will not pay for coring, testing on the core samples, or excavation costs, even if the drilled shaft is accepted.

If the IQF or the Engineer determines a drilled shaft is not acceptable, the DBT shall submit a plan for remedial action to the IQF and the Engineer for acceptance. Have an Ohio Registered Engineer prepare, sign, seal, and date calculations and working drawings for all foundation elements affected by the remedial action plan. Have a second Ohio Registered Engineer check, sign, seal and date the calculations and working drawings. The preparer and checker shall be two different Engineers.

**089 CORING OF DRILLED SHAFT CONCRETE**: If the CSL test results indicate possible defects in the drilled shaft, the IQF or the Engineer may require coring of the drilled shaft concrete to obtain samples in the area of the possible defect. If directed by the IQF or the Engineer, obtain core samples in accordance with ASTM D 2113 for the full length of the possible defect plus 3 feet (1 meter) above and below the possible defect, or as directed by the IQF or the Engineer. Obtain core samples with a minimum diameter of 3.0 inches (75 mm).

Use either a conventional double-tube, swivel-type core barrel with split liners or a wireline core barrel with split inner liners. Use a new diamond coring bit. Replace the coring bit and core barrel as necessary to achieve a high percentage of core recovery.

Record an accurate log of the coring. Place the core samples in a crate and properly mark showing the depth below the top of the drilled shaft for each core sample. Submit the core samples and four copies of the coring logs to the IQF and the Engineer (two copies each).

**10 GROUTING TUBES AND HOLES**: After CSL testing and coring of the drilled shaft concrete is complete, remove all water from the access tubes and any cored holes. If the tubes extend above the top of the drilled shaft reinforcing, cutoff the tubes below the top of the drilled shaft reinforcing. Fill the tubes and core holes with grout.

**STATE OF OHIO**
**DEPARTMENT OF TRANSPORTATION**

**SPECIFICATION FOR**
**Gamma-Gamma Testing For Drilled Shafts**
**CUY-90-14.52 (PID 77332)**

**January 2010**



**01 DESCRIPTION**: This work consists of evaluating the structural integrity of drilled shafts using the Gamma-Gamma testing method. Access tubes installed to conduct the Crosshole Sonic Logging (CSL) shall be used to conduct the Gamma-Gamma Testing except for the demonstration shaft(s) where additional access tubes shall be installed for conducting Gamma-Gamma Testing only in accordance with this specification. The Gamma-Gamma Testing shall be conducted on the first four (4) installed Contract drilled shafts in addition to the Demonstration Drilled Shaft(s). All subsequently installed Contract drilled shafts shall be tested for structural integrity utilizing the Crosshole Sonic Logging testing method only. The work also consists of core drilling of concrete to confirm possible defects.

**02 MATERIALS**: Refer to the Specification for Crosshole Sonic Logging (CSL) Testing for Drilled Shafts for materials requirements.

**03 NDT CONSULTANT:** Retain an experienced Nondestructive Testing (NDT) consultant to perform or supervise the Gamma-Gamma testing. The NDT consultant shall have at least two years experience in Gamma-Gamma testing. Submit to the IQF for acceptance a resume of the credentials of the proposed NDT consultant at least 14 Calendar Days before constructing the drilled shafts.

**094 INSTALLATION OF ACCESS TUBES:** Refer to the Specification for Crosshole Sonic Logging (CSL) Testing for Drilled Shafts for requirement on the installation of access tubes.

**05 INSTALLATION OF ADDITIONAL ACCESS TUBES FOR DEMONSTRATION DRILLED SHAFT(S):** Refer to the Specification for Crosshole Sonic Logging (CSL) Testing for Drilled Shafts for requirements on the installation of access tubes. Install four (4) additional access tubes which are to be placed to the outside of the reinforcing cage and are to be equally spaced around the perimeter of the reinforcing cage. Place the access tube in a manner that meets the clearance requirements of the ODOT Bridge Design Manual. Additional access tubes are not required for Contract drilled shafts.

## 06 TEST METHOD

### Part 1: Gamma-Gamma Logging System Requirements

**A. Apparatus:**

1. *Gamma-Gamma Probe.* The probe shall consist of a rigid cylinder containing a gamma particle-emitting source and a gamma particle detector. The probe shall be suspended by a cable of sufficient design and length that is safely capable of raising and lowering the gamma-gamma probe within a nominal 2-inch polyvinyl chloride (PVC) inspection pipe to desired test depths.
   a) The gamma particle-emitting source shall be Cesium-137 in sealed source form.
   b) The gamma-gamma probe detector shall consist of a proven method of gamma detection, such as Geiger-Mueller or scintillation-based counters.

2. *Readout Device.* The detector shall be connected to a readout device that is capable of displaying and/or recording counts, densities and sampling duration or probe speed.

3. *Cable and Winch.* The cables affixed to the probe shall be of sufficient strength and durability to raise and lower the probe safely and at a controlled rate of speed. Any winch mechanism utilized shall not damage the cables or compromise data collected in the test. A means of determining and recording probe depth shall be provided.

**B. Density Precision:**

1. The gamma-gamma probe shall possess a minimum density precision of 1.0 $lb/ft^3$. Density precision shall be defined as the standard deviation from the mean value of gamma count rate at a particular sample time.

2. For gamma-gamma logging, only sample times exceeding the minimum required to obtain the density precision of 1.0 $lb/ft^3$ shall be used for logging

shafts. Probes that are unable to achieve a density precision of 1.0 lb/ft$^3$ shall not be utilized for gamma-gamma logging.

3. Determination of density precision and minimum sample time shall be in conformance with Attachment A of this test method.

### C. Radius of Detection

1. The radius of detection ($R_d$) of the gamma-gamma probe shall be a minimum of 3.0-inches but less than 4.5-inches in concrete with density between 140 and 160 lb/ft$^3$. Radius of Detection shall be defined as the distance from the center of the probe cylinder to the maximum distance where a change in material density has a discernable effect upon the collected data.

2. The radius of detection shall be determined by means of an Influence Determination Unit according to the requirements detailed in Attachment B of this test method.

### D. Qualification Report

1. Each gamma-gamma probe shall have a report signed and stamped by a Registered Engineer certifying and providing supporting documentation of compliance with the above provisions for gamma-gamma logging system requirements.

## Part 2: Instrument Calibration and Functionality Limit Determination

### A. Instrument Calibration

1. Prior to use for gamma-gamma logging and at time intervals not to exceed one year, the gamma-gamma probe and readout device shall be calibrated to correlate count rate to concrete density.

2. Calibration parameters shall be determined by monitoring count rates performed in the concrete calibration samples described in Attachment C. A minimum of three concrete calibration samples, as described in Attachment C, shall be utilized for the calibration procedure. The following procedure shall be used:

   a. Place the probe in one of the calibration concrete samples. Verify that the source is a minimum of 6-inches above the bottom of the sample and that the detector is a minimum of 6-inches below the top of the sample.

   b. With the probe at a constant depth, record a minimum of 50 count readings within each concrete calibration sample.

c. Calculate the arithmetic mean of the count readings using the following equation for each concrete calibration sample:

$$C_{mean} = \frac{C_1 + \cdots + C_n}{n}$$

Where,

$C_{mean}$ = Mean of counts
$C_n$ = $n^{th}$ count
n = total number of counts

d. Compute the natural logarithm of the mean count ($C_{MLC}$) for each of the concrete calibration samples as shown below:

$$C_{MLC} = \ln(C_{mean})$$

e. Plot the $C_{MLC}$ obtained in Step (d) for each concrete calibration sample. Plot the known concrete densities on the x-axis and the corresponding $C_{MLC}$ values on the y-axis.

f. Using the least squares method, establish the best-fit linear representation to the points plotted in Step (d). This linear fit should take on the form of:

$C_{MLC} = a\gamma + b$ which may be rewritten as: $\gamma = \frac{(C_{MLC} - b)}{a}$

where,

$\gamma$= concrete density
*a* = slope of best-fit line
*b* = y-intercept of best-fit line

3. Current calibration records shall be documented in the form of a graph, with supporting tabular data, date calibration was performed, and equation coefficients.

**B. Determination of Standard Reference Functionality Limits**

1. Using the standard reference described and qualified in accordance with Attachment D, the standard reference functionality limits shall be determined at time intervals not to exceed one year. The functionality limits shall also be re-established after any maintenance operations are performed on said gamma-gamma probe. Functionality limits shall be unique for each probe and source combination and shall only be determined for those probe and source combinations previously qualified in accordance with Attachment D.

2. The procedure for determination of functionality limits shall not be performed where the influence of any other radioactive source can be detected above background levels.

3. Place the standard reference in the location where it will typically be located at the beginning of the workday.

4. Place the probe in the standard reference. Ensure that the source is a minimum of 4.5-inches from the exterior base of the standard reference and that the detector is a minimum of 4.5-inches from the top of the standard reference.

5. Take a minimum of 200 independent consecutive readings. Calculate the mean gamma count rate and standard deviation of gamma count rate using the following equations:

$$N_{ref,mean} = \frac{(N_{ref,1} + \ldots + N_{ref,i})}{i}$$

$$\sigma_{ref} = \sqrt{\frac{\sum_{n=1}^{i} (N_{ref,n} - N_{ref,mean})^2}{(i-1)}}$$

where,
$N_{ref,\ mean}$ = mean gamma count rate
$\sigma_{ref}$ = standard deviation of gamma count rate
i = number of independent consecutive readings

6. Determine Lower Functionality Limit (LFL) and Upper Functionality Limit (UFL) in accordance with the following equations:

$$LFL = 0.947 * N_{ref,\ mean} - 1.95 * \sigma_{ref}$$
$$UFL = 1.03 * N_{ref,\ mean} + 1.95 * \sigma_{ref}$$

7. Each standard reference and gamma-gamma probe combination shall have a report signed and stamped by a Registered Engineer certifying compliance with the above provisions and documenting the LFL and UFL values.

8. The independent readings from both the vertical and horizontal conditions shall be documented in tabular form.

## Part 3: Requirements for Access Tube Construction

Refer to the Specification for Crosshole Sonic Logging (CSL) Testing for Drilled Shafts for requirement on the installation of access tubes.

## Part 4: Field Testing Procedures

### A. Functionality Evaluation Using the Standard Reference

1. A functionality evaluation shall be performed at the start of each workday for each gamma-gamma probe used. A functionality evaluation should also be utilized anytime the performance of the gamma-gamma probe is in question.

2. The functionality evaluation procedure shall not be performed where the influence of any other radioactive source can be detected above background levels.

3. Place the probe in the standard reference. Ensure that the source is a minimum of $R_d$ from the bottom of the standard reference and that the detector is a minimum of $R_d$ from the top of the standard reference, where, Rd = Radius of Detection, as determined in Attachment B

4. Take four independent consecutive readings and calculate the daily mean count rate.
   $N_{daily,mean} = (N_1+N_2+N_3+N_4)/4$

   where,
   $N_{daily, mean}$ = daily mean count rate
   $N_1$, $N_2$, $N_3$, $N_4$ = individual count rate readings

   Record the four individual count rate readings ($N_1$, $N_2$, $N_3$, $N_4$) and the daily mean ($N_{daily, mean}$) in the *Functionality Verification Log* form. An example of this form is included in Attachment E. The *Functionality Verification Log* shall be retained as a permanent record.

5. Verify that the daily mean ($N_{daily, mean}$) is greater than the LFL and less than the UFL as determined in Part 2-B-6. If the above condition is not satisfied, the gamma-gamma probe shall not be used to perform the acceptance testing.

6. If the gamma-gamma probe has failed the functionality evaluation, the probe shall be serviced by qualified personnel, any malfunction remedied, and a new LFL and UFL shall be determined in accordance with Part 2-B prior to the performance of further acceptance testing.

### B. Preparation of the Shaft

1. Verify that the inspection pipes are free of any standing water, debris or obstructions.
2. Complete the form titled *Gamma-Gamma Test Set-Up Sheet*.
   a. Complete the general information section at the top of the form.
   b. Complete the plan view drawing with the appropriate number and inspection pipe locations.

c. If the distance between inspection tubes is not uniform, measure the distance between each inspection pipe pair and record the information in the “Spacing Dist.” column.
d. Using a measuring tape or equivalent, measure the total length of each inspection pipe and record the lengths in the “Taped Depth” column. Record inspection pipe stick up in the “Stickup” column.
e. If any kinks, obstructions or water are present in any of the inspection pipes, enter the appropriate information in the lower section of the form. An example of the *Gamma-Gamma Test Set-Up Sheet* is included in Attachment E.

3. Inspection pipes shall be marked prior to testing using a permanent marking pen or suitable permanent marking device with the support location number, shaft number and tube number. An inspection tube to be tested may contain the marking:

### C. Testing

Perform the Gamma-Gamma test after the concrete develops sufficient strength and before de-bonding of access tubes from the surrounding concrete. The IQF may direct a longer minimum time if the drilled shaft concrete contains a retarding admixture or uses a mix design that results in a longer setting time for the drilled shaft concrete.

1. Lower the probe into the inspection pipe.

2. When extracting the probe, acquire readings at a depth interval not to exceed 1.5-inches at the minimum sampling time period as determined in Part 1-A-1 to obtain the required density precision. Record data on the form titled *Gamma-Gamma Test Set-Up Sheet*. An example of this form is included in the attachments.

3. The tube and the-shaft top shall be spray painted with orange paint upon completion of gamma-gamma logging.

## Part 5: Data Analysis and Reporting

### A. Analysis of Data

1. Apply the calibration parameters determined in Part 1-B from the concrete calibration samples to the raw count readings and obtain bulk concrete densities. Verify that the data set contains no logging errors, duplicated data or skipped data points.

2. Determine the mean, $\gamma_{mean}$, of a set of bulk densities. A set will consist of data collected from a single inspection pipe, using the same instrument, within the same time period.

where, $\gamma_{mean}$ = the mean of the group of bulk densities, as calculated by:

$$\gamma_{mean} = \frac{(\gamma_1 + \cdots + \gamma_n)}{n}$$

3. Data that shall not be included in the calculation of the $\gamma_{mean}$ include:
    a. Repetitive data points collected at a single depth.
    b. Data affected by the presence of water within the inspection tube.
    c. Data collected at the top of the shaft where the reading(s) were influenced by the gamma detector component of the probe exiting the shaft concrete.
    d. Data collected in inspection tubes above the top of the concrete in a shaft.
    e. Data affected by the presence of anomalous zones of concrete.
    f. Data that cause the population distribution to be statistically non-normal.

4. In the event that a known difference in the steel reinforcement schedule exists in a segment of a shaft that affects the apparent mean, a separate mean shall be generated and utilized as the mean for that portion of the data.

5. Subtract the mean from each data point in the set to obtain a data set that reflects the variation from the mean.

6. Plot the data obtained in Step (3) with the depth on the y-axis and the variation from mean bulk density on the x-axis.
7. Repeat Step (1) through Step (4) for all inspection tubes contained within an individual shaft and plot that data as a single plot.

## B. Standard Deviation Analysis

1. Determine the standard deviation, $\sigma_\gamma$, of a compilation of bulk densities. A compilation will consist of data collected from all shafts, of the same diameter and type of construction, using the same instrument, within the same time period. If the test is a comparative retest, use the previously calculated standard deviation.

2. Standard deviation in a compilation of shafts is determined by evaluating the data relative to the following criteria:

$$\sigma_\gamma = \sqrt{\frac{\sum_{n=1}^{i}(N_{\gamma,n})^2}{i-1}}$$

where,
$N_{\gamma,n}$ = difference of density of a data point from the mean as determined by Section 5-A-4
$\sigma_\gamma$ = standard deviation of density of the data compilation
$i$ = number of data points

3. Data that shall not be included in the calculation of the $\sigma_\gamma$ include:
    a. Repetitive data points collected at a single depth.
    b. Data affected by the presence of water within the inspection tube.

c. Data collected at the top of the shaft where the reading(s) were influenced by the gamma detector component of the probe exiting the shaft concrete.
d. Data collected in inspection tubes above the top of the concrete in a shaft.
e. Data affected by the presence of anomalous zones of concrete
f. Data that cause the population distribution to be statistically non-normal.

4. If the value calculated in Section 5-B-2 is less than 2.5 $lb/ft^3$, use a standard deviation of 2.5 $lb/ft^3$. If the value calculated in Step 5-B-2 exceeds 3.75 $lb/ft^3$, use a standard deviation of 3.75 $lb/ft^3$.

5. Multiply the value obtained for standard deviation by –2.0 to obtain a "Minus Two Standard Deviations" (-2SD) value. Multiply the value obtained for standard deviation by –3.0 to obtain a "Minus Three Standard Deviations" (-3SD) value.

6. Plot at all depths and on all plots of individual shafts developed in Part 5-A, the values for –2SD and –3SD. Utilize symbols or formatting that permits the lines corresponding to –2SD and –3SD to be distinguished from data points.

## C. Anomaly Identification

1. Anomalies in a shaft are determined by evaluating the data points developed in Part 5-A to the minus three standard deviation criteria developed in Part 5-B. Shafts are determined to be anomalous if:
   a. In a single inspection pipe over any 0.5-foot or greater depth interval, all of the density readings have a value less than the determined value for minus three standard deviations.

   b. In the same inspection pipe identified anomalous by Step 5-C-1-a, within 1-foot vertical extent of the previously identified anomaly, any data point that falls below the value for minus three standard deviations shall be considered a contiguous anomalous region.

   c. In all inspection pipes adjacent to inspection pipes already identified as anomalous, if at least one data point within 2-feet vertically of the adjacent pipe anomaly falls below the value for minus three standard deviations, that pipe is also anomalous.

## D. Anomaly Extent

- Where anomalies have been identified by Gamma-Gamma Logging in Part 5-C, the maximum longitudinal and cross-sectional extent of the anomaly shall be delineated.

- When an isolated anomaly has been identified in a single inspection pipe solely by Part 5-C-a, the vertical extent of an anomaly shall be from the minimum depth where a data point is less than three standard deviations from the mean to the maximum depth where a point is less than three standard deviations. Where multiple tubes are identified as anomalous at the same depth, or the same inspection pipe or adjacent inspection pipe is identified as anomalous by Section 5-1-b or 5-1-c, the vertical extent of an anomaly shall be from the minimum depth where a data point in any of the associated pipes is less than three standard deviations to the maximum depth where a point in any of the associated pipes is less than three standard deviations. Where multiple anomalies are detected in a single shaft and are identified by the Engineer experienced in gamma-gamma logging to be independent of each other, the anomalies shall be delineated and sized separately.

- For evaluation of cross-sectional area based upon Gamma-Gamma Logging, a representative sample method shall be utilized to approximate maximum cross section affected. When additional information is provided that permits the Engineer experienced with gamma-gamma logging to alter the representative sample assessment, engineering judgment shall be utilized to determine the new probable maximum extent.

## E. REPORTS

The report of the gamma-gamma logging, data analysis and results shall include the following information when applicable, and shall be signed and stamped by a Registered Professional Engineer:

1. General.
    a. Project identification,
    b. Project location,
    c. Owner,
    d. Shaft Designer,*
    e. Foundation Designer,*
    f. Shaft contractor,*
    g. Location of shaft(s),
    h. Designation and location of nearest test boring with reference to the shaft or group of shafts being tested,*
    i. Log of nearest test boring,*

2. Shaft Installation.
    a. Drilled shaft Diameter,
    b. Drilled shaft length,
    c. Drilled shaft cutoff elevation,
    d. Drilled shaft tip elevation,
    e. Type and size of drilling equipment,*
    f. Type of slurry used,*
    g. Description of concrete mix,*
    h. Reinforcement details,*
    i. Inspection pipe placement,*
    j. Concrete placement method,*
    k. Date of construction,*

    l. Drilled shaft layout with shaft numbers,*

3. Gamma-Gamma Logging.
    a. Date of logging,
    b. Brief description of testing equipment,
    c. Number of drilled shafts logged,
    d. Location of inspection tube obstructions,
    e. Log of PVC coupler locations,*
    f. Calibration date, data, and plot,*
    g. Plots showing variation from mean bulk density (x-axis) versus depth or elevation (y-axis),
    h. Description and explanation of adjustments made to instrumentation or data (if any),
    i. Summary of any unusual occurrences during testing,
4. Conclusions.
    a. Identification of anomalies.
    b. Delineation of Affected Tubes
    c. Vertical Location and Extent of Anomalies
    d. Estimated Percentage of Cross- Sectional Area
    e. Recommendations

*Information delineated by an asterisk shall be available on request, but may not be required for individual gamma-gamma logging reports.

The following reports shall be completed and signed and stamped by a Registered Professional Engineer prior to the performance of any acceptance testing using these specifications.

a. Gamma-Gamma Probe Qualification Report (see Part 1-D-1).
b. Instrument Calibration Report (see Part 2-A-2).
c. Standard Reference Qualification Report (see Part 2-B-7)

## 07 EVALUATIONS OF TEST RESULTS

The IQF will evaluate the Gamma-Gamma test results and determine if the drilled shaft construction is acceptable. If the Gamma-Gamma test results indicate possible defects in the drilled shaft, the IQF or the Engineer may require coring of the drilled shaft to obtain samples in the area of the possible defect, or excavation of the drilled shaft to examine the condition of the concrete. The IQF or the Engineer may require testing of the core samples. The IQF and the Engineer will consider the Gamma-Gamma test results, the condition of the concrete as shown by core samples, results of testing on the core samples, and other information when determining the acceptability of the drilled shaft. The DBT shall not proceed with construction of substructures or structures above a drilled shaft until the IQF and the Engineer have accepted the drilled shaft.

If examination of the drilled shaft concrete confirms the presence of a defect in the drilled shaft, then the Department will not pay for coring, testing on the core samples or excavation costs, even if the drilled shaft is accepted.

If the IQF or the Engineer determines a drilled shaft is not acceptable, the DBT shall submit a plan for remedial action to the IQF and the Engineer for acceptance. Have an Ohio Registered Engineer prepare, sign, seal, and date calculations and working drawings for all foundation elements affected by the remedial action plan. Have a second Ohio Registered Engineer check, sign, seal and date the calculations and working drawings. The preparer and checker shall be two different Engineers.

## 08 CORING OF DRILLED SHAFT CONCRETE

If the Gamma-Gamma test results indicate possible defects in the drilled shaft, the IQF or the Engineer may require coring of the drilled shaft concrete to obtain samples in the area of the possible defect. If directed by the IQF or the Engineer, obtain core samples in accordance with ASTM D 2113 for the full length of the possible defect plus 3 feet (1 meter) above and below the possible defect, or as directed by the IQF or the Engineer. Obtain core samples with a minimum diameter of 3.0 inches (75 mm).

Use either a conventional double-tube, swivel-type core barrel with split liners or a wireline core barrel with split inner liners. Use a new diamond coring bit. Replace the coring bit and core barrel as necessary to achieve a high percentage of core recovery.

Record an accurate log of the coring. Place the core samples in a crate and properly mark showing the depth below the top of the drilled shaft for each core sample. Submit the core samples and four copies of the coring logs to the IQF and the Engineer (two copies each).

## 09 GROUTING OF ACCESS TUBES AND CORE HOLES

**Refer to the Specification for Crosshole Sonic Logging (CSL) Testing for Drilled Shafts for requirement on the installation of access tubes.**

# ATTACHMENT A

## Determination of Density Precision for a Gamma-Gamma Probe

**A. Scope**

This Attachment provides the procedures for the determination of density precision for a gamma-gamma probe.

**B. Apparatus**

The determination of density precision requires the utilization of concrete calibration samples as described in Attachment C.

**C. Procedure**

1. The density precision and sample time shall be determined for all new probe and source combinations and configurations and shall be determined at intervals not to exceed four years. Density precision and sample times shall also be recalculated when maintenance operations are performed on said gamma-gamma probe detectors. The density precision and minimum required sample time shall be unique for each probe and source combination.

2. Place the probe in Concrete Calibration Sample #2. The concrete calibration sample shall conform to the requirements contained in Attachment C.

3. Ensure that the source is a minimum of (0.33) $S_{sd}$ from the bottom of the concrete calibration sample and that the detector is a minimum of (0.33) $S_{sd}$ from the top of the concrete calibration sample, where:

   $S_{sd}$ = distance between the probe's source and detector

4. Select a trial sample time.

5. Acquire a minimum of 200 independent consecutive readings at the trial sample time in Concrete Calibration Sample #2. If any variation exists in the actual measured sample times for individual readings, any point where the actual sample time for data collection was more than 10 percent higher or lower than the trial sample time shall be deleted. A minimum of 200 data points shall remain after deletion, or the trial sample time readings shall be completely reacquired.

6. Acquire a minimum of 50 independent consecutive points in each of the remaining concrete calibration samples. When performing testing within each concrete calibration sample, verify that the source is a minimum of (0.5) $S_{sd}$ above the bottom of the sample and that the detector is a minimum of (0.5) $S_{sd}$ below the top of the sample,

   where: $S_{sd}$ = distance between the probe's source and detector

7. With the probe at a constant depth, record a minimum of 50 count readings within each remaining calibration concrete sample.

8. Calculate the arithmetic mean of the count readings using the following equation for each concrete calibration sample, including Concrete Calibration Sample #2:

$$N_{mean} = \frac{(C_1 + \cdots + C_n)}{n}$$

where,

$N_{mean}$ = Average of counts
$C_n$ = nth count
n = total number of individual count readings

9. Compute the natural logarithm of the mean count ($C_{MLC}$) for each of the calibration concrete samples as shown below:

$$C_{MLC} = \ln (N_{mean})$$

where,

$N_{mean}$ = Average of counts
$C_{MLC}$ = natural logarithm of mean gamma count rate

10. Plot the $C_{MLC}$ obtained in Step 9 with the known density of each concrete calibration sample. Plot the concrete densities on the x-axis and the corresponding $C_{MLC}$ values on the y-axis.
11. Using the least squares method, establish the best-fit linear representation to the points plotted in Step 10. This linear fit should take on the form of:

$$C_{MLC} = a\gamma + b$$

which may be rewritten as:

$$\gamma = \frac{(C_{MLC} - b)}{a}$$

where,

$C_{MLC}$ = natural logarithm of mean gamma count rate
$\gamma$= concrete density
a = slope of best-fit line
b = y-intercept of best-fit line

12. Determine the standard deviation for the natural logarithm of the gamma count rate readings obtained in Concrete Calibration Sample #2.

$$\sigma_{ccs2} = \sqrt{\frac{\sum_{n=1}^{i} (N_{CCS2,n} - N_{CCS2,mean})^2}{i}}$$

where,
$\sigma_{CCS2}$ = Standard Deviation of the natural logarithm of the Gamma Count Rates for Concrete Calibration Sample #2

$N_{CCS2,\ mean}$ = Arithmetic Mean of the natural logarithm of the Gamma Count Rates for Concrete Calibration Sample #2
$N_{CCS2,\ n}$ = Value of the natural logarithm of the Gamma Count Rate number "n"
n = total number of count readings (n >200)

13. Calculate the natural logarithm of the gamma count rates corresponding with the mean minus one standard deviation.

$$C_{\mu-\sigma}=N_{CCS2,\ mean}-\sigma_{CCS2}$$

where,
$N_{CCS2}$, mean = Arithmetic Mean of the natural logarithm of the Gamma Count Rates for Concrete Calibration Sample #2

$\sigma_{CCS2}$ = Standard Deviation of the natural logarithm of the Gamma Count Rates for Concrete Calibration Sample #2
$C_{\mu-\sigma}$=Mean the natural logarithm of the Count Rate minus One Standard Deviation.

14. Determine the densities corresponding to the $N_{CCS2,\ mean}$ and $C_{\mu-\sigma}$ values.

$$D_{\mu} = \frac{N_{CCS2,mean} - b}{a}$$

$$D_{\mu-\sigma} = \frac{(C_{\mu-\sigma} - b)}{a}$$

a = The slope of the calibration line, as determined in Step 11
b = The "y-intercept" of the calibration line, as determined in Step 11
Dm= Density at the Mean
$D_{\mu-\sigma}$ =Density at One Deviation below Mean
$N_{CCS2,\ mean}$ = Arithmetic Mean of the natural logarithm of the Gamma Count Rates for Concrete Calibration Sample #2
$C_{\mu-\sigma}$= Mean the natural logarithm of the Count Rate minus One Standard Deviation

15. Obtain the precision density, $P_d$, by calculating the arithmetic difference between $D_{\mu}$ and $C_{\mu-\sigma}$.

$$P_d=|D_{\mu} - D_{\mu-\sigma}|$$

where,
$P_d$ = Density Precision
$D_\mu$ = Density at the Mean
$C_{\mu-\sigma}$= Density at One Deviation below Mean

16. Verify that $P_d$ is 1.0 lb/ft$^3$ or less. If $P_d$ exceeds 1.0 lb/ft$^3$, the probe may not be utilized for gamma-gamma logging at the selected trial sample time. If a longer sampling time is possible, a new trial sample time may be selected and this process repeated. If no sample time is capable of generating a $P_d$ of 1.0 lb/ft$^3$ or less, the probe shall not be utilized for gamma-gamma logging.

17. The sample time utilized shall not be greater than or less than the manufacturer's recommended sample time range. For calculated sample times exceeding the manufacturer's maximum sample time, the probe shall not be utilized for acceptance testing. For calculated sample times less than the manufacturer's sample time range, the sample time shall be increased to the minimum recommendation by the manufacturer.

18. The smallest sample time that is within the range recommended by the probe manufacturer and possessing a precision density of 1.0 lb/ft$^3$ or less shall be referred to as the minimum sample time. Gamma-Gamma logging shall not be performed at a sampling time less than the minimum sample time.

# ATTACHMENT B

## Determination of Radius of Detection for a Gamma-Gamma Probe

**A. Scope**
This Attachment specifies the procedures and equipment required for the determination of radius of detection for a gamma-gamma probe.

**B. Apparatus**
The determination of radius of detection requires the utilization of an Influence Determination Unit.

**C. Procedure**

1. The radius of detection shall be determined for all new probe and source combinations and configurations and verified at intervals not to exceed four years. Radius of detection shall also be recalculated when maintenance operations are performed on said gamma-gamma probe detectors. The radius of detection shall be unique for each probe and source combination.

2. Radius of Detection shall be determined in an Influence Determination Unit (IDU) as described in Attachment E. The Radius of Detection shall not be determined in a location where any other radiation source can be detected above background levels or any intermittent radiation source is present.

3. For all probes less than 1.85-inches in outside diameter, centralizing devices shall be used to center the gamma-gamma probe within the nominal 2-inch Schedule 40 PVC inspection pipe for the IDU. Centralizers shall not be placed around or between the probe source and detector or interfere with normal probe operation. Centralizers shall maintain the gamma-gamma probe within 0.1-inch of the longitudinal centerline of the inspection tube.

4. Place the gamma-gamma probe within the IDU. Push the gamma-gamma probe through the IDU to a point flush with the end of the IDU inspection tube.

5. For each radius of detection data collection run, pull the gamma-gamma probe through the IDU, collecting readings at intervals not to exceed every 1.5-inches. The sampling time for intervals shall be equal to or greater than the minimum sampling time to obtain the required density precision. Stop data collection when the source or detector emerges from the IDU.

6. Perform a minimum of three radius of detection data collection runs within the IDU.

7. Plot the gamma count rate for each data point collected versus the position along the IDU.

8. Determine the Low Density Baseline and High Density Baseline. The Low Density Baseline shall be the relatively consistent value for the gamma count rate from 1 foot to 3 foot within the IDU, ignoring boundary condition effects. The High Density Baseline shall be the relatively consistent value for the gamma count rate from 15 to 18 feet within the IDU, ignoring boundary

condition effects. If the Low Density Baseline and High Density Baseline cannot be determined, the probe may not be utilized for acceptance testing.

9. Determine the length of the transition zone, LTZ. The length of the transition zone shall be defined as the distance between where the measured readings begin to deviate from low-density baseline to the point where no deviation relative to the high density is observable above background scatter.

10. Determine the Radius of Detection, utilizing the following equation:

$$R_d = (L_{tz} - S_{sd})/12$$

where,
$R_d$ = The Radius of Detection (in)
$L_{tz}$ = Length of the Transition Zone (in)
$S_{sd}$ = Source to detector spacing (in)

11. For the gamma-gamma probe to be utilized for acceptance testing the following equation must be satisfied:
3-inch $\leq R_d \leq$ 4.5-inch where, $R_d$ = Radius of Detection

# ATTACHMENT C

## Gamma-Gamma Probe Density Calibration Concrete Calibration Samples

### A. Scope

This Attachment specifies the requirements for the concrete calibration samples for use with a gamma-gamma probe.

### B. Apparatus

Each concrete sample used to calibrate the gamma-gamma probe to density shall consist of a concrete mass of fixed shape. Concrete samples shall cover the range of densities anticipated for the evaluation of concrete integrity. A minimum of three samples shall be used to establish the relationship between count rate and concrete density. The concrete samples shall conform to the ranges of densities as shown in the following table:

| Sample | Minimum (lb/ft$^3$) | Maximum (lb/ft$^3$) |
|---|---|---|
| 1 | 100 | 120 |
| 2 | 140 | 160 |
| 3 | 180 | 200 |

PVC Inspection pipes described in Part 3-A-2 shall be cast into the concrete samples. The minimum dimensions of the calibration concrete samples are provided in Attachment E.

# ATTACHMENT D

## Construction and qualifications of a Standard Reference for a Gamma-Gamma Probe

**A. Scope**

This Attachment specifies the construction and qualification of a standard reference for use with a gamma-gamma probe.

**B. Apparatus**

1. Standard Reference.
    a. The dimensions of the standard reference are provided in Attachment E.
    b. The standard reference shall be constructed using Portland cement concrete or a cement grout mix such that the block is homogeneous with a minimum density of 145 lb/ft$^3$.
    c. The standard reference shall be fabricated such that boundary conditions around the standard reference do not alter the gamma count rate by more than 3 percent of the mean gamma count rate.

2. *Gamma-Gamma Probe*. The gamma-gamma probe shall meet the specifications described in Part 1.

**C. Procedure**

1. A specific combination of probe, source, and standard reference may be qualified for use by verification that the effect of boundary conditions does not alter the gamma count rate by more than 3 percent of the mean gamma count rate.

2. The initial qualification shall be unique for each probe and source combination, and need only be performed once for each specific combination of probe, source and standard reference proposed for use.

3. The procedure for standard reference initial qualification shall not be performed where the influence of any other radioactive source can be detected above background levels.

4. The initial qualification procedure for the standard reference shall not be performed closer than 15 feet from any large or massive object above ground level elevation including but not limited to structures, vehicles and trees. Initial qualification shall be performed on a smooth and level Portland cement or asphaltic concrete slab of 3-inches minimum thickness as shown in Attachment E.
5. Place the standard reference in the vertical position while upon the slab as shown in Attachment E.
6. Place the probe in the standard reference. Ensure that the source is a minimum of Rd from the bottom of the standard reference and that the detector is a minimum of Rd from the top of the standard reference,

where, $R_d$ = Radius of Detection as determined in Attachment B.

7. Acquire a minimum of 200 independent consecutive readings at the unit's operating sample time as determined in Attachment A. Calculate the mean gamma Count rate for vertical position ($\mu_v$) using the following equation:

$$\mu_v = \frac{(V_1 + \cdots + V_n)}{n}$$

where,

$\mu_v$ = mean gamma count rate
$V_n$ = nth count
n = total number of counts

8. Place the standard reference in the horizontal position while upon the slab as shown in Attachment E.

9. Acquire a minimum of 200 independent consecutive readings at the unit's operating sample time as determined in Attachment A. Calculate the mean gamma count rate for horizontal condition ($\mu_h$) using the following equation:

$$\mu_h = \frac{H_1 + \cdots + H_n}{n}$$

10. The following equation shall be satisfied for the standard reference to receive initial qualification:

$$2 * \frac{|\mu_h - \mu_v|}{\mu_h + \mu_v} \leq 0.03$$

where,
$\mu_h$ = mean gamma count rate for horizontal condition
$\mu_v$= mean gamma count rate for vertical condition

# ATTACHMENT E

# FORMS AND FIGURES

# Functionality Verification Log

| Standard Reference Serial Number | Probe Make / Model | Winch / Probe / Source Serial Numbers |
|---|---|---|
| Date Functionality Limits Determined | Lower Functionality Limit (LFL) | Upper Functionality Limit (UFL) |

| Date | Operator | Functionality Determination Readings | | | | |
|---|---|---|---|---|---|---|
| | | $N_1$ | $N_2$ | $N_3$ | $N_4$ | **$N_{daily,mean}$** |
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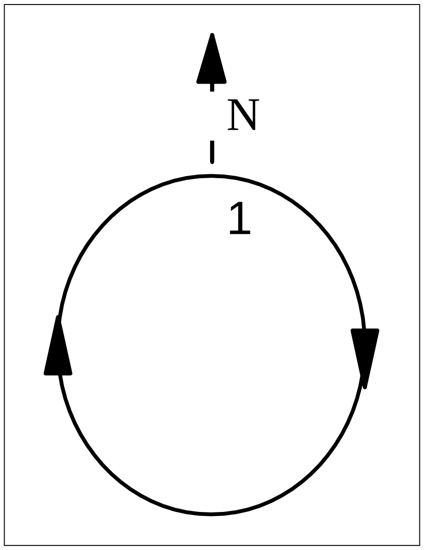
# Gamma-Gamma Test Set-up Sheet

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Structure Name | | | | Date Tested | | | |
| Bridge No. | | E.A. | | Operator | | | |
| Dist./Co./Rte. | | | | Dia. | | Spec. Length | |
| Support No. | | Pile No. | | No. of Inspection Tubes | | | |




| Tube No. | | Taped Depth | | Probed Depth | | Spacing Dist. | | Stick-Up | | Wet/Dry or Water Depth |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | | |
| | | | | | | | | | | |
| 2 | | | | | | | | | | |
| | | | | | | | | | | |
| 3 | | | | | | | | | | |
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| 4 | | | | | | | | | | |
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| 5 | | | | | | | | | | |
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| 6 | | | | | | | | | | |
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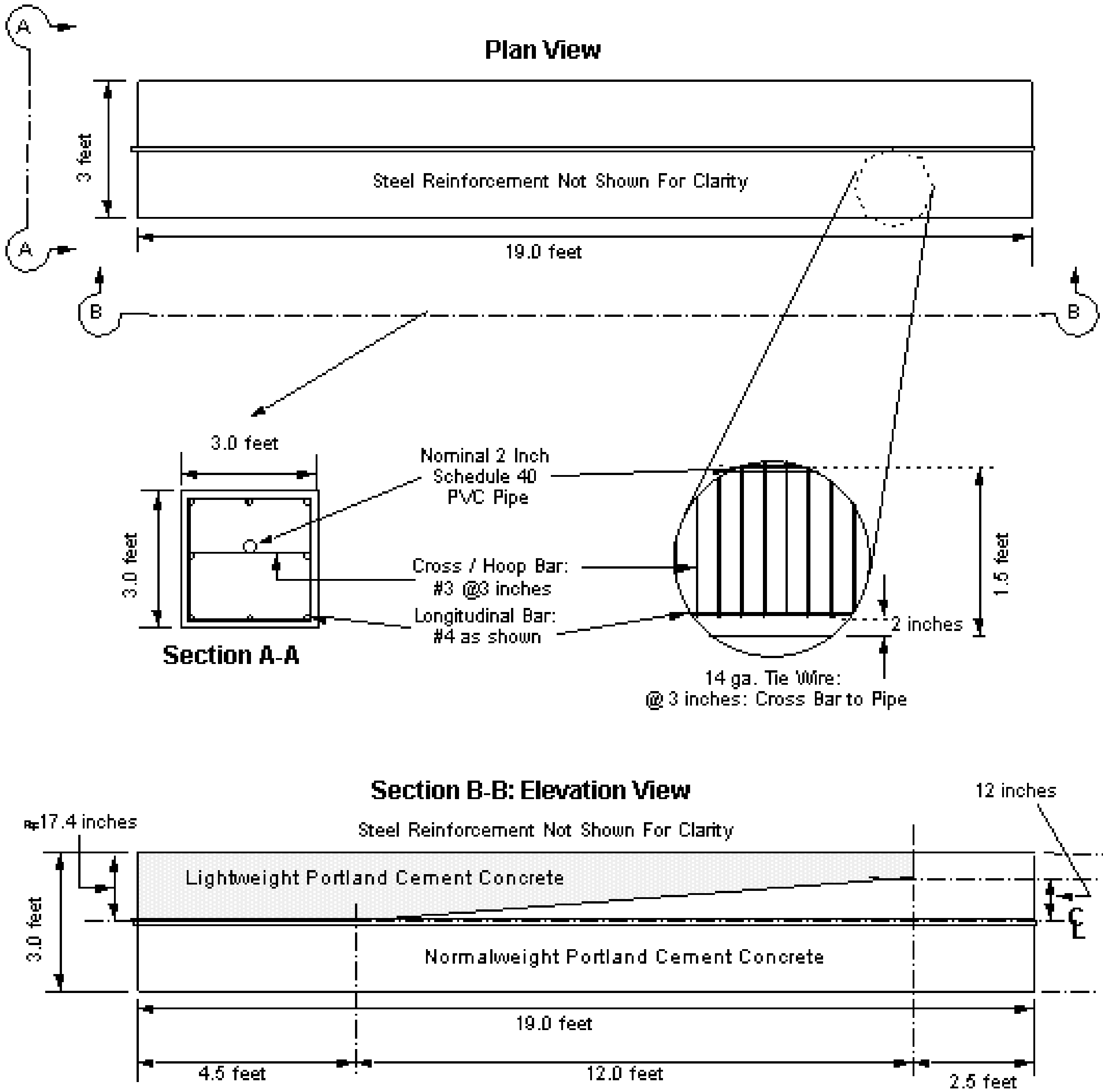
| 7 | | | | | | | | | | |
| | | | | | | | | | | |
| 8 | | | | | | | | | | |
| | | | | | | | | | | |

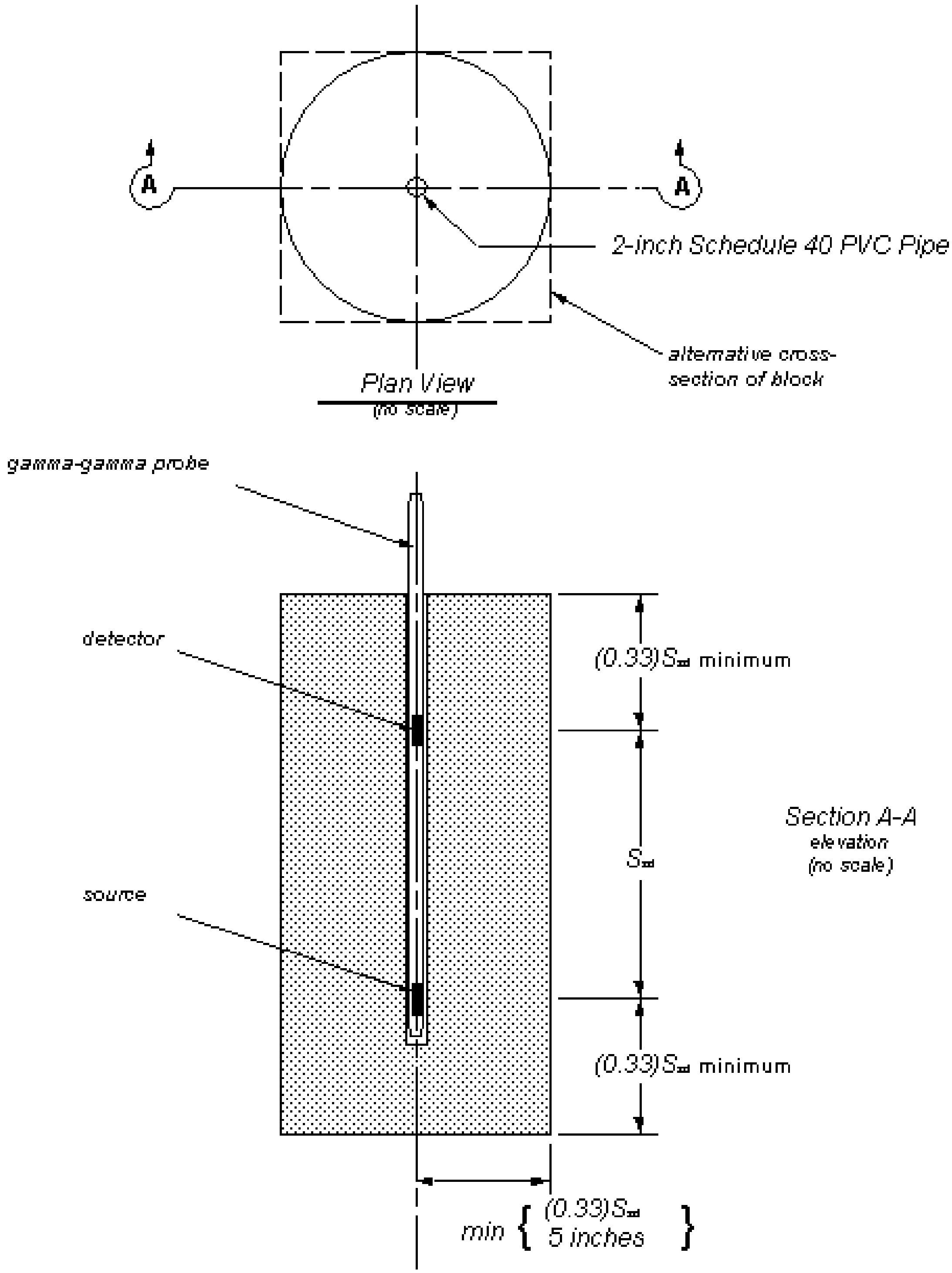
| | | | | | |
|---|---|---|---|---|---|
| Calibration No. | | | Missing Tubes | Yes / No | |
| Calibration Date | | | Blocked Tubes | Yes / No | |
| Daily Functionality | Yes / No | | Water in Tubes | Yes / No | |
| | | | | | |
| Winch SN | | Probe SN | | Source SN | |

Remarks / Observations

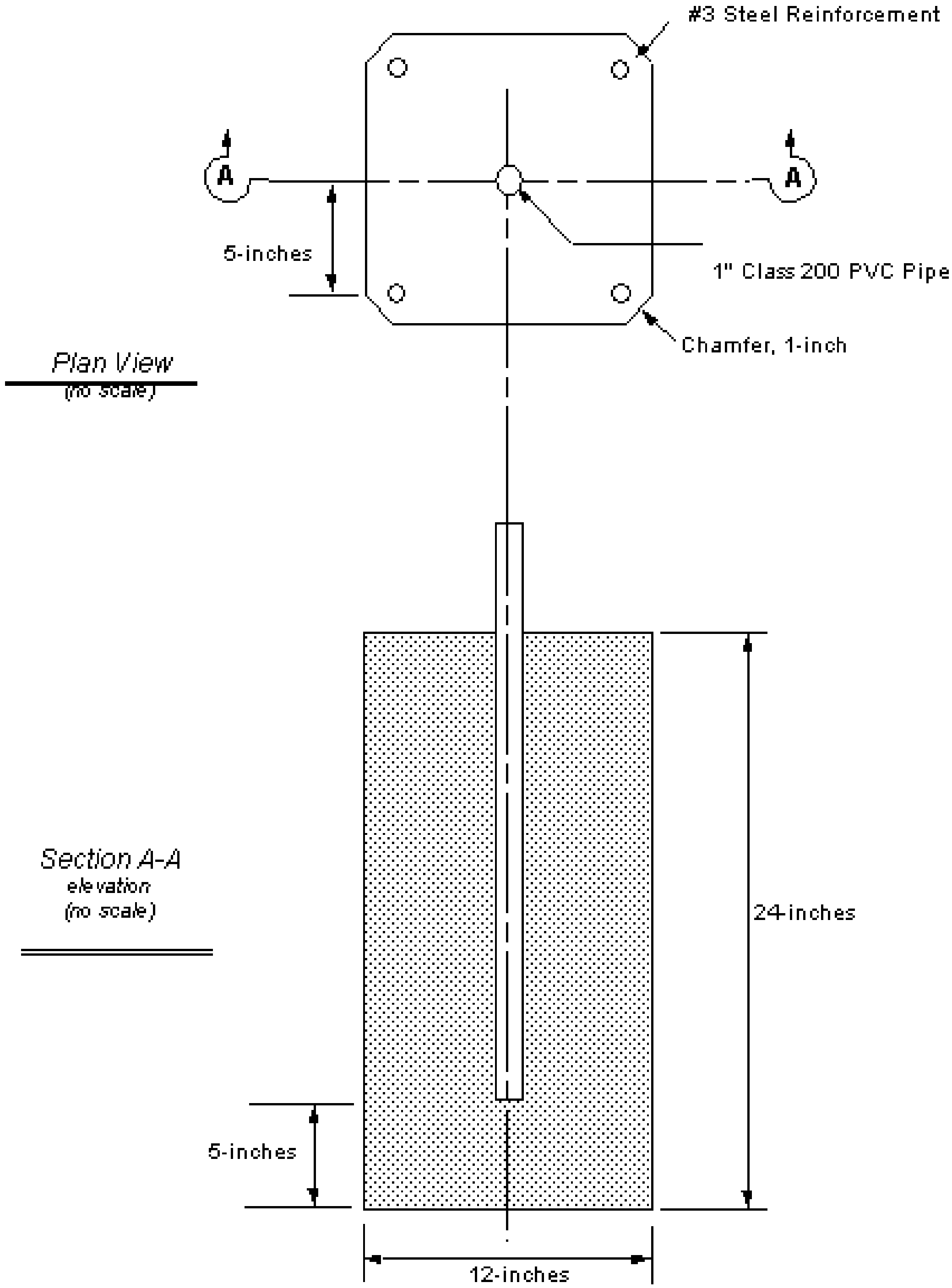
| |
|---|
| |
| |
| |



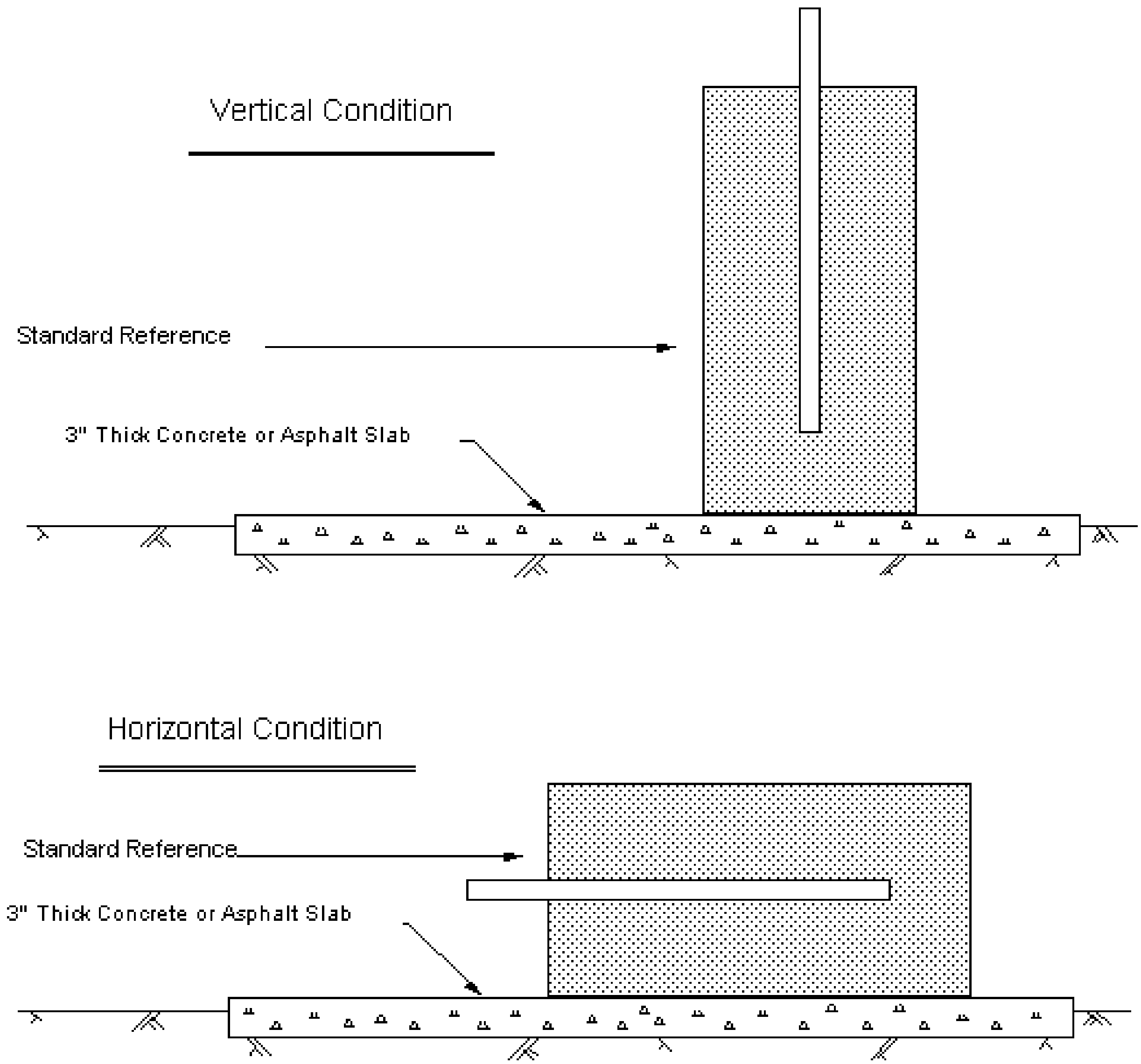

# Influence Determination Unit




# Concrete Calibration Sample




# Typical Standard Reference Details




For both Vertical and Horizontal Condition, do not perform test closer than 15 feet to any large object or where the influence of any other radioactive source can be detected above background levels.

## Standard Reference: Boundary Conditions