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METHOD OF ASCERTAINING THE HOMOGENEITY OF CONCRETE IN CAST-IN-DRILLED-HOLE (CIDH) PILES USING THE GAMMA-GAMMA TEST METHOD

CAUTION: Prior to handling test materials, performing equipment setups, and/or conducting this method, testers are required to read **"SAFETY AND HEALTH"** in Part 6 of this method. It is the responsibility of the user of this method to consult and use departmental safety and health practices and determine the applicability of regulatory limitations before any testing is performed.

OVERVIEW

This procedure ascertains the homogeneity of concrete density for the evaluation of construction of Cast-In-Drilled-Hole (CIDH) piles. Concrete used in CIDH piles is required to be dense and homogeneous throughout the length and cross section of the pile.

This test method is divided into the following sections:

1. Gamma-Gamma Logging System Requirements
2. Instrument Calibrations and Functionality Limit Determination
3. Requirements for Inspection Tube Construction
4. Field Testing Procedures
5. Data Analysis and Reporting
6. Safety and Health

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 CIDH piles. 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 Appendix 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 affect upon the collected data.

2. The radius of detection shall be determined by means of an Influence Determination Unit according to the requ6irements detailed in Appendix B of this test method.

D. QUALIFICATION REPORT

1. Each gamma-gamma probe shall have a report signed and stamped by a Civil Engineer licensed in the State of California 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 Appendix C. A minimum of three concrete calibration samples, as described in Appendix 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:

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

   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 (c) 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,

γ = 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 Appendix 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 Appendix 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:

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

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

where,

$N_{ref,\,mean}$ = mean gamma count rate
σ_{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 Civil Engineer licensed in the State of California 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 and retained for a minimum of five years.

PART 3. REQUIREMENTS FOR INSPECTION PIPE CONSTRUCTION

A. INSPECTION PIPES

1. Prior to concrete placement and gamma-gamma testing, CIDH piles shall be prepared with the installation of inspection pipes to allow for the passage of the gamma-gamma probe.

2. Inspection pipes shall be Schedule 40 PVC pipes with a nominal diameter of 2-inches. PVC couplers are permitted to facilitate pipe lengths in excess of that which is commercially available.

3. Each inspection pipe shall be securely capped on bottom and shall have watertight couplers to provide a clean and unobstructed 2-inches diameter clear opening from 3-feet above the pile cutoff down to the bottom of the reinforcing cage. If pile cutoff is below the ground surface or working platform, inspection pipes shall be extended to 3 feet above the ground surface or working platform. Approved covers or railings shall be provided and inspection pipes shall be located as necessary to minimize exposure of testing personnel to potential falling hazards.

4. Inspection pipes shall be placed around the pile inside the outermost spiral or hoop reinforcement at a spacing no greater than 1.5-inches clear of the outermost spiral or hoop reinforcement.

5. Inspection pipes shall be placed around the pile, inside the outermost spiral or hoop reinforcement, and a minimum of 3-inches clear of the vertical reinforcement, at a uniform spacing not exceeding 2-foot 9-inches measured along the circle passing through the centers of the inspection pipes. A minimum of two inspection pipes per pile shall be used. When the vertical reinforcement is not bundled and each bar is not more than 1-inch in diameter, inspection pipes may be placed 2-inches clear of the vertical reinforcement.

6. The inspection pipes shall be placed so to provide the maximum diameter circle that passes through the centers of the inspection pipes while maintaining the clear spacing required herein.

7. The inspection pipes shall be installed in straight alignment and securely fastened in place to prevent displacement or misalignment during installation of the reinforcement and placement of concrete in the hole. The CIDH piles shall be constructed so that the relative distance of inspection tubes to steel shall remain constant.

8. Where the dimensions of the CIDH pile do not permit inspection pipes to be placed adequately to meet the design and testing requirements, the Engineer experienced with gamma-gamma logging may permit inspection pipes to be placed closer than the required clearance of Section 3-A-5. Inspection tube placement must be in parallel alignment to the vertical reinforcing steel and maximize distance to vertical steel and proximity to the interior of the outermost steel reinforcement cage spiral or hoop.

9. Inspection pipes shall be completely dry at the time of testing, although water may be placed inside the inspection pipes to facilitate construction provided it is completely purged before testing.

10. In cases where a gamma-gamma probe has been calibrated in concrete calibration samples with inspection tubes filled with water and radius of detection and density precision have been performed under water and determined to be within the prescribed limits, gamma-gamma logging may be performed in an inspection tube completely filled with water. Testing shall only be conducted under water at the discretion of the Engineer experienced with gamma-gamma logging. Where prior approval for testing under water has not been given for a particular pile, all gamma-gamma logging shall be conducted in dry inspection pipes.

B. INSPECTION PIPE VERIFICATION AND REPORTING REQUIREMENTS

1. After placing concrete and before performing the gamma-gamma tests, each inspection pipe shall be tested by passing a rigid cylinder of the same or greater dimension and geometry as the gamma probe through the complete length of pipe. In addition, all standing water present within the inspection pipe shall be removed.

2. A log shall be kept to identify the depths, with respect to the plane of pile cutoff, of any PVC couplers used in the inspection pipes and provided to the Engineer.

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,

   R_d = Radius of Detection, as determined in Appendix B

4. Take four independent consecutive readings and calculate the daily mean count rate.

$$N_{daily,mean} = \frac{\left(N_1 + N_2 + N_3 + N_4\right)}{4}$$

   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 Appendix E. The *Functionality Verification Log* shall be retained as a permanent record for a minimum of five years.

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 PILE

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 "Stick-up" 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 Appendix E.

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

   B3R-P5-T4

   which would indicate:

   Bent 3 Right, Pile No. 5, Inspection Tube No.

   The orientation of the inspection tube numbering shall be recorded relative to magnetic North or fixed reference points and be recorded on the Setup Sheet. Inspection pipe numbering shall be preserved until a Cast-In-Drilled Hole pile is accepted.

C. TESTING

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 pile 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, γ_{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,

   γ_{mean} = the mean of the group of bulk densities, as calculated by:

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

3. Data that shall not be included in the calculation of the γ_{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 CIDH pile where the reading(s) were influenced by the gamma detector component of the probe exiting the pile concrete.

   d) Data collected in inspection tubes above the top of the concrete in a CIDH pile.

   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 CIDH pile 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 pile and plot that data as a single plot.

B. STANDARD DEVIATION ANALYSIS

1. Determine the standard deviation, σ_γ, of a compilation of bulk densities. A compilation will consist of data collected from all CIDH piles, 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 piles is determined by evaluating the data relative to the following criteria:

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

where,

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

Data that shall not be included in the calculation of the σ_γ 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 CIDH pile where the reading(s) were influenced by the gamma detector component of the probe exiting the pile concrete.

d) Data collected in inspection tubes above the top of the concrete in a CIDH pile.

e) Data affected by the presence of anomalous zones of concrete.

f) Data that cause the population distribution to be statistically non-normal.

3. 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.

4. 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.

5. Plot at all depths and on all plots of individual piles 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 pile are determined by evaluating the data points developed in Part 5-A to the minus three standard deviation criteria developed in Part 5-B. Piles 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

1. 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.

2. 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 pile 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.

3. 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

1. 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 Civil Engineer registered in the State of California:

   a) General.
   Project identification,
   Project location,
   Owner,
   Pile Designer,*
   Foundation Designer,*
   Pile contractor,*
   Location of pile(s),
   Designation and location of nearest test boring with reference to the pile or group of piles being tested,*
   Log of nearest test boring,*

   b) Pile Installation.
   Pile Diameter,
   Pile length,
   Pile cutoff elevation,
   Pile tip elevation,
   Type and size of drilling equipment,*
   Type of slurry used,*
   Description of concrete mix,*
   Reinforcement details,*
   Inspection pipe placement,*
   Concrete placement method,*
   Date of construction,*
   Pile layout with pile numbers,*

   c) Gamma-Gamma Logging.
   Date of logging,
   Brief description of testing equipment,
   Number of piles logged,
   Location of inspection tube obstructions,
   Log of PVC coupler locations,*
   Calibration date, data, and plot,*
   Plots showing variation from mean bulk density (x-axis) versus depth or elevation (y-axis),
   Description and explanation of adjustments made to instrumentation or data (if any),
   Summary of any unusual occurrences during testing,

   d) Conclusions.
   Identification of anomalies.
   Delineation of Affected Tubes
   Vertical Location and Extent of Anomalies
   Estimated Percentage of Cross-Sectional Area
   Recommendations

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

2. The following reports shall be completed and signed and stamped by a Civil Engineer registered in the State of California prior to the performance of any acceptance testing using CTM 233.

   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)

PART 6. SAFETY AND HEALTH

Prior to handling, testing or disposing of any waste materials, testers are required to read: Part A, Section 5.0, Part B, Sections 5.0, 6.0 and 10.0 and Part C, Section 1.0 of Caltrans Laboratory Safety Manual.

All personnel shall be licensed by all applicable regulatory agencies and shall strictly adhere to all safety and health requirements including applicable Code of Safe Work Practices and site-specific restrictions. Users of this method do so at their own risk.

APPENDIX A

DETERMINATION OF DENSITY PRECISION FOR A GAMMA-GAMMA PROBE

A. SCOPE

This Appendix 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 Appendix 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 Appendix 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:

$$N_{mean} = \frac{C_1 + \ldots + C_n}{n}$$

   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:

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

where,

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

10. Plot the 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 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
γ = 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.

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

where,

σ_{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 ($n \geq 200$)

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
σ_{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
D_{μ} = 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_μ and $D_{\mu-\sigma}$.

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

    where,

    P_d = Density Precision
    D_μ = Density at the Mean
    $D_{\mu - \sigma}$ = 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.

APPENDIX B

DETERMINATION OF RADIUS OF DETECTION FOR A GAMMA-GAMMA PROBE

A. SCOPE

This Appendix 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 Appendix 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, L_{TZ}. 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:

$$3\text{-inch} \leq R_d \leq 4.5\text{-inch}$$

where,

R_d = Radius of Detection

APPENDIX C

GAMMA-GAMMA PROBE DENSITY CALIBRATION CONCRETE CALIBRATION SAMPLES

A. SCOPE

This Appendix 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 Appendix E.

APPENDIX D

CONSTRUCTION AND QUALIFICATION OF A STANDARD REFERENCE FOR A GAMMA-GAMMA PROBE

A. SCOPE

This Appendix 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 Appendix 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 Appendix E.

5. Place the standard reference in the vertical position while upon the slab as shown in Appendix E.

6. 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,

   R_d = Radius of Detection as determined in Appendix B.

7. Acquire a minimum of 200 independent consecutive readings at the unit's operating sample time as determined in Appendix A. Calculate the mean gamma

count rate for vertical position (μ_v) using the following equation:

$$\mu_v = \frac{V_1 + ... + V_n}{n}$$

where,

μ_v = mean gamma count rate
V_n = n^{th} count
n = total number of counts

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

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

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

where,

μ_h = mean gamma count rate
H_n = n^{th} count
n = total number of counts

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,

μ_h = mean gamma count rate for horizontal condition
μ_v = mean gamma count rate for vertical condition

APPENDIX E

FORMS AND FIGURES

End of Text
(California Test 233 contains 21 pages)

Functionality Verification Log

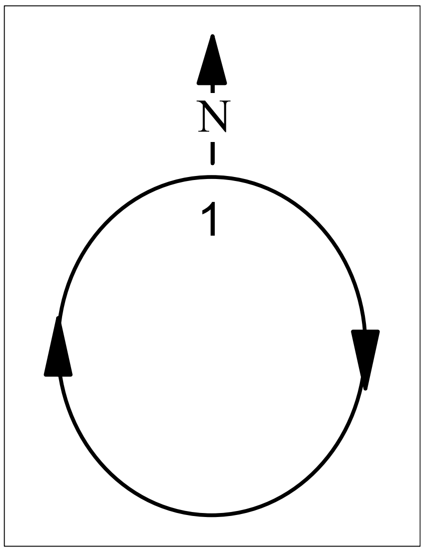
Standard Reference Serial Number	Probe Make / Model	Winch / Probe / Source Serial Numbers
Date Functionality Limits Determined	Lower Functionality Limit (LFL)	Upper Functionality Limit (UFL)

Date	Operator	Functionality Determination Readings				
		N_1	N_2	N_3	N_4	$\mathbf{N_{daily,mean}}$

Caltrans

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		

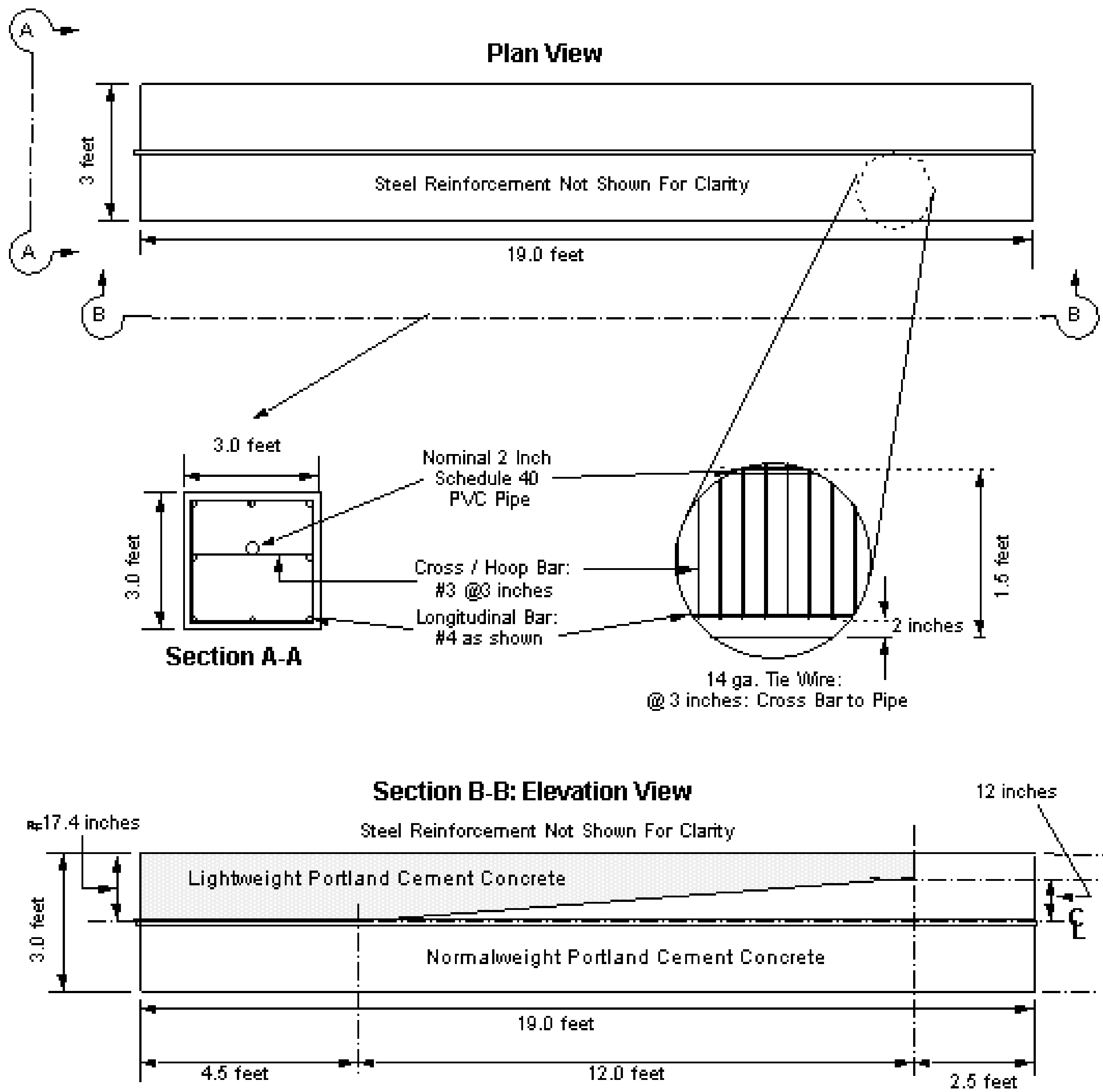


Tube No.		Taped Depth		Probed Depth		Spacing Dist.		Stick-Up		Wet/Dry or Water Depth
1										
2										
3										
4										
5										
6										
7										
8										

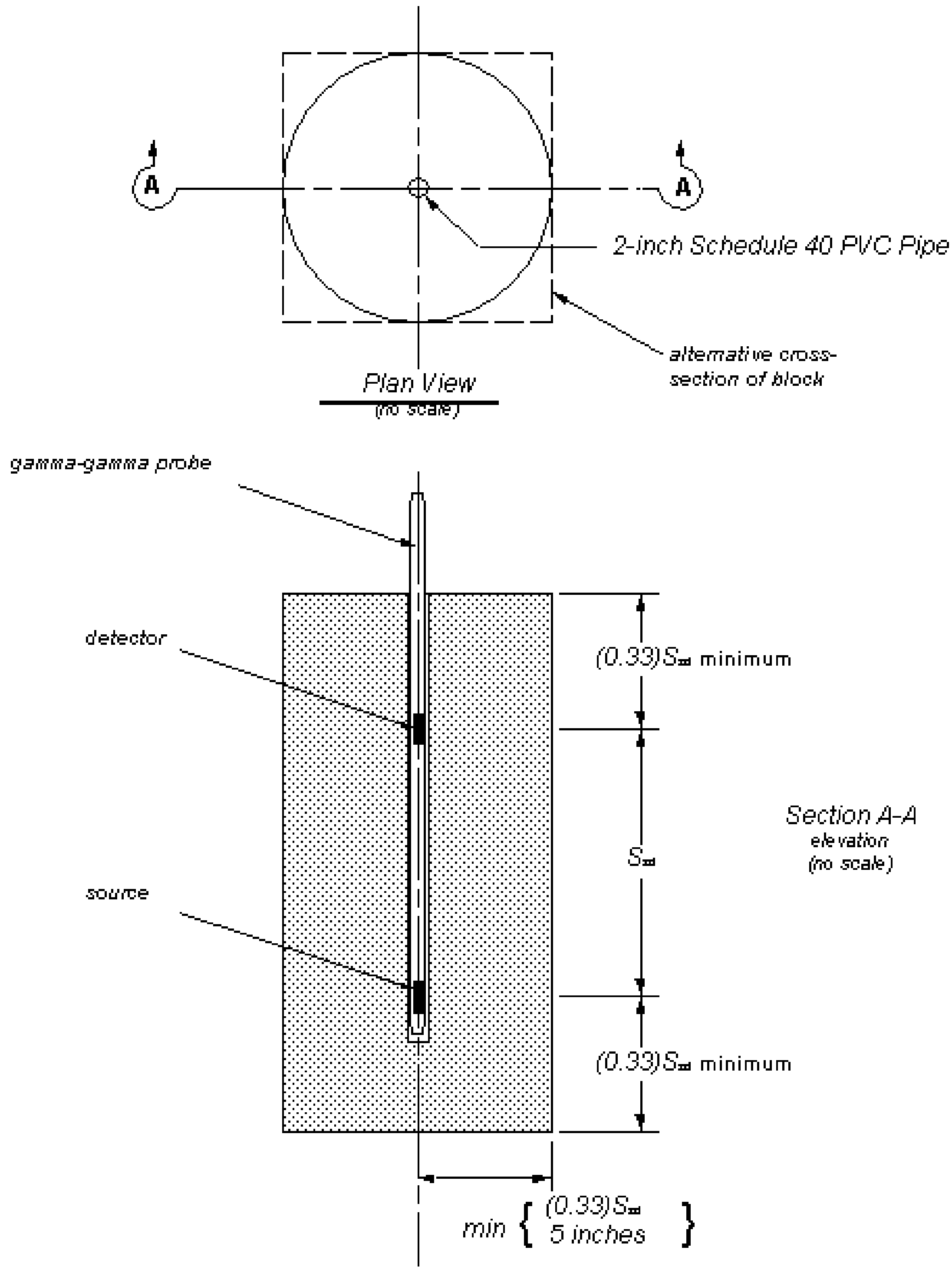
Calibration No.		Missing Tubes	Yes / No
Calibration Date		Blocked Tubes	Yes / No
Daily Functionality	Yes / No	Water in Tubes	Yes / No

Winch SN		Probe SN		Source SN	

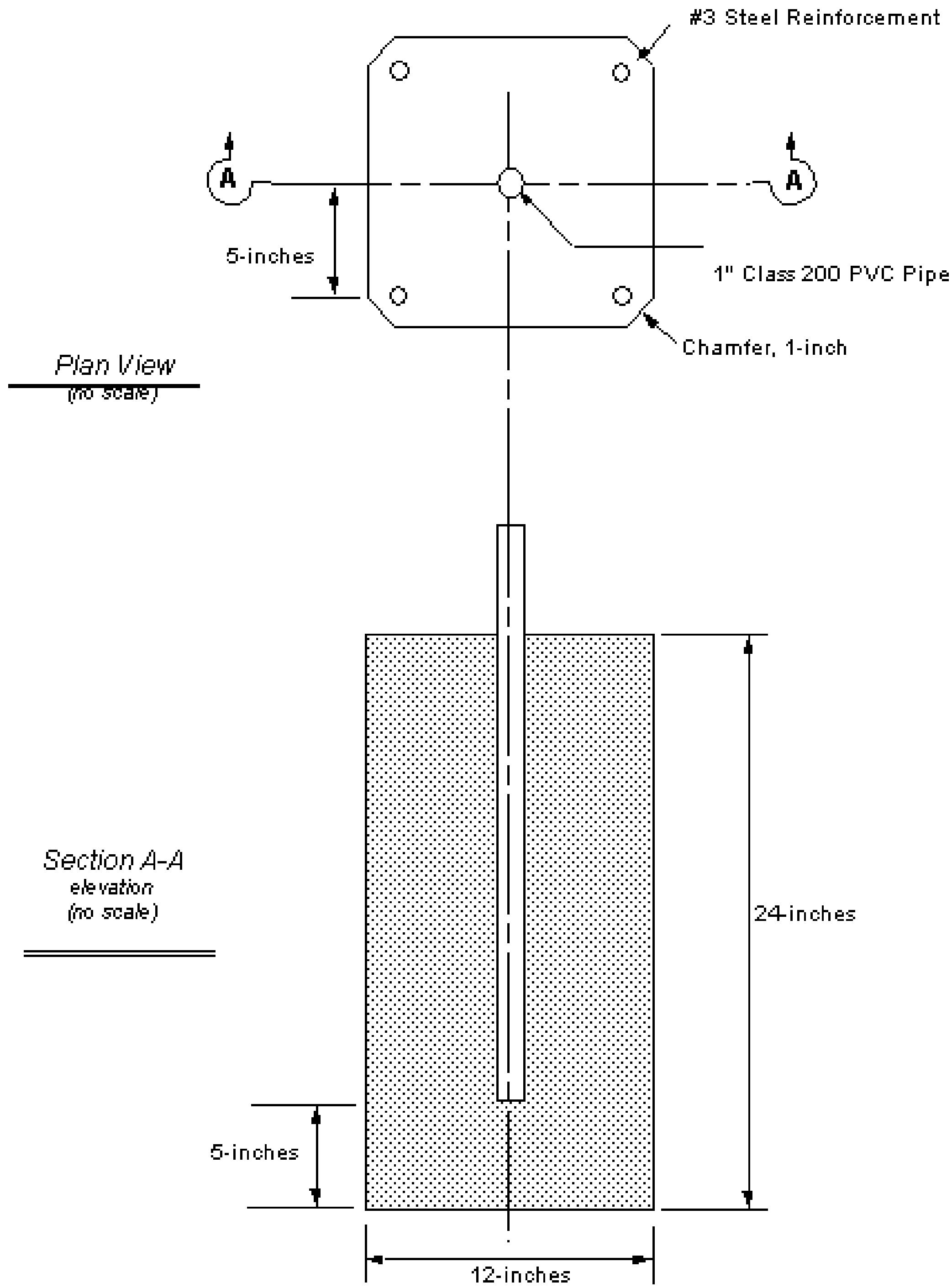
Remarks / Observations



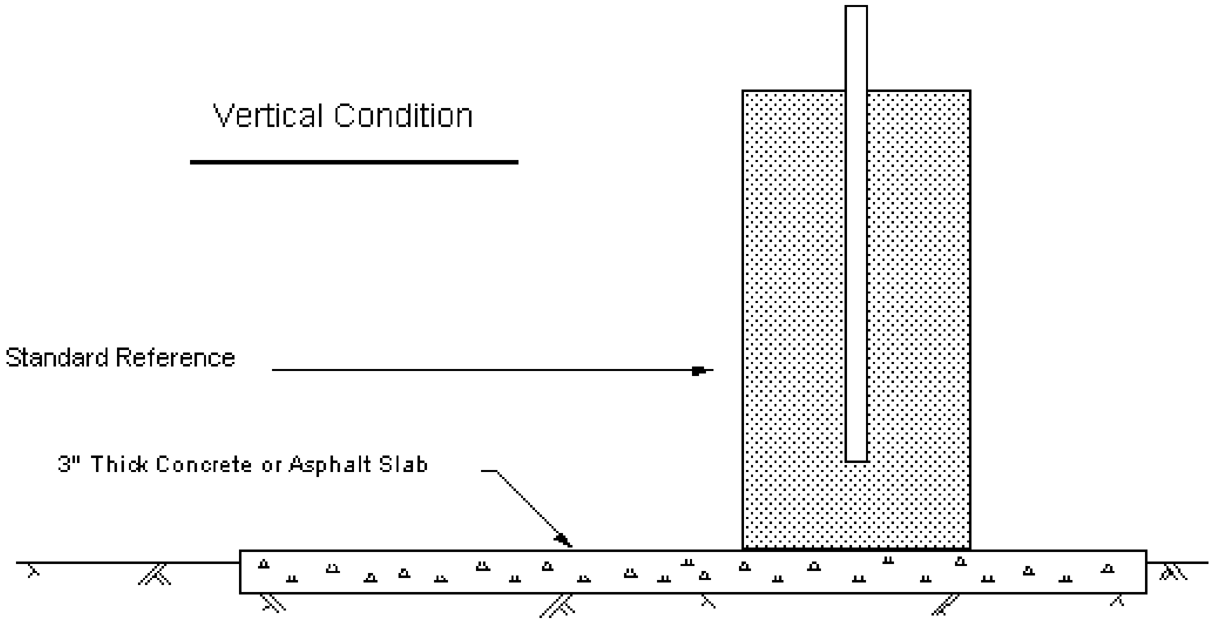
Influence Determination Unit

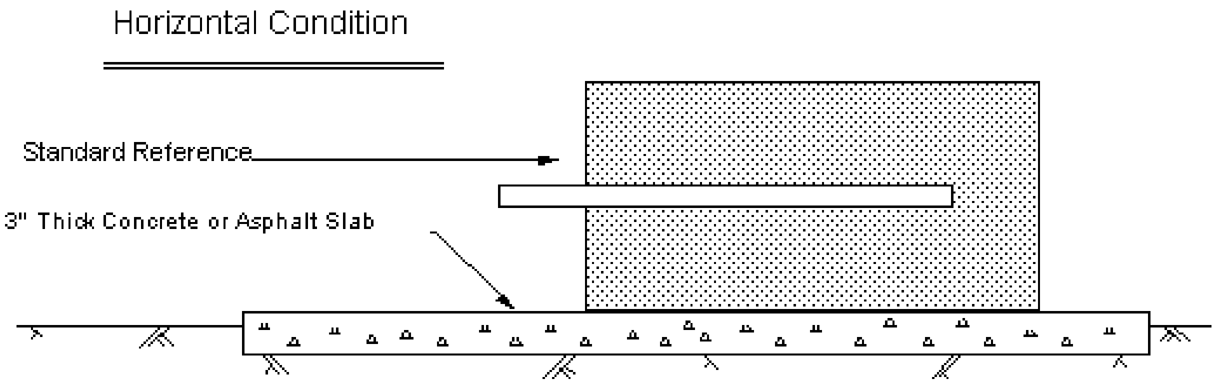


Concrete Calibration Sample



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