U.S. Department of Energy Office of Independent Oversight Criteria Review and Approach Document	Subject: Nuclear Facility Construction – Structural Concrete Director, Office of ES&H Evaluations Date: 05/29/09 Criteria Lead, Nuclear Facility Construction – Structural Concrete Date: 5/29/09	HS: HSS CRAD 64-15 Rev: 0 Eff. Date: 05/29/2009 Page 1 of 17

1.0 PURPOSE

Within the Office of Independent Oversight, the Office of Environment, Safety and Health (ES&H) Evaluations' (HS-64) mission is to assess the effectiveness of those environment, safety and health systems and practices used by field organizations in implementing Integrated Safety Management and to provide clear, concise, and independent evaluations of performance in protecting our workers, the public, and the environment from the hazards associated with Department of Energy (DOE) activities and sites. A key to success is the rigor and comprehensiveness of our process; and as with any process, we continually strive to improve and provide additional value and insight to field operations. Integral to this is our commitment to enhance our program. Therefore, we have revised our Inspection Criteria, Approach, and Lines of Inquiry for internal use and also we are making them available for use by DOE line and contractor assessment personnel in developing and implementing effective DOE oversight and contractor self-assessment and corrective action processes on this WEB page.

2.0 APPLICABILITY

The following Inspection Criteria document is approved for use by the Office of ES&H Evaluations.

3.0 FEEDBACK

Comments and suggestions for improvements on these Inspection Criteria, Approach, and Lines of Inquiry can be directed to the Director of the Office of ES&H Evaluations on (301) 903-5392.

Inspection Criteria

The following DOE directives and industry standards are applicable to the extent that they are referenced in design basis documents and contract specifications:

- Quality assurance programs are established and implemented in accordance with 10CFR830, Subpart A, *Quality Assurance Requirements,* ASME NQA-1, *Quality Assurance Requirements for Nuclear Facilities Applications,* DOE Order 414.1C, *Quality Assurance,* and DOE Order 226.1A, *Implementation of DOE Oversight Policy.*
- The construction of safety-related concrete structures for nuclear facilities meets the requirements of American Concrete Institute standard ACI 349-01, *Code Requirements for Nuclear Safety Related Concrete Structures.*
- Test methods and acceptance criteria for concrete materials are in accordance with: American Society for Testing and Materials (ASTM) C150 for cement, ASTM C618 for flyash, ASTM C33 for aggregate, and ASTM C260, C424, and/or C1017 for chemical additives (concrete admixtures). Methods for water testing meet requirements specified in the U.S. Army Corps of Engineers Handbook of Concrete and Cement, Test Methods CRC 440-63 and 406-79.
- Concrete manufacturing meets requirements specified by National Ready Mixed Concrete Association (NRMCA) standards.
- Batch plant mixer efficiency is tested in accordance with ASTM C-94.

Inspection Activity

Observe construction activities and review records and design documentation to assess the quality of concrete manufacturing and placement and to determine if requirements specified by design basis documents, contracts, and applicable codes and standards have been met.

- Review concrete construction procedures to determine if they are appropriate and adequate for procurement, manufacture, testing and placement of concrete and to determine if they specify adequate hold points and provide adequate controls for design changes.
- Observe ongoing construction work to determine if concrete work activities and the quality of work meet the requirements of applicable specifications, procedures, drawings, and codes.
- Observe quality control (QC) inspection activities and examine completed concrete work to assess the effectiveness of the QC program. Review the qualification of QC inspection personnel.
- Review records documenting quality of completed concrete installation. Include records of receipt inspection, concrete testing and placement, nonconformance/deviation reports, training and qualification, and quality assurance (QA) audits.

Inspection Lines of Inquiry

- Manufacture of Concrete
  - Do contractor test procedures and procurement specifications require that concrete ingredients meet applicable industry standards?
  - Do test results and vendor certifications indicate that applicable specifications were met?
  - Is storage of concrete ingredients controlled so that each ingredient is traceable to an

approved source?

- Are cement and flyash protected from moisture?
- Is aggregate protected from contamination by debris, dirt, other materials, or by mixing with other sizes of aggregates?
- Do compressive strength tests and mix properties (e.g. slump, air entrainment, density, etc.) indicate that concrete mix designs for safety class structures meet requirements specified in design basis documents and contract specifications?
- Is a new mix design established and tested when sources of concrete materials are changed, or when mix properties are changed?
- Is freshly mixed concrete tested to verify chlorides are not present in excess of limits?
- Has the batch plant been inspected to verify that equipment performs properly (e.g., inspection of rotation speed, timing, and blade wear) and has it been certified to National Ready Mixed Concrete Association (NRMCA) standards?
- Have batch plant scales and meters been calibrated through their full operating range at the required frequency and to specified tolerances? Do scales read zero when unloaded?
- Have batch plant mixer-efficiency tests been performed at proper interval in accordance with ASTM C-94?
- Are batch plant water meters and admixture dispensers properly calibrated?
- Are batch water quality requirements met and is the amount of water added adjusted to account for moisture-content of aggregates? Are aggregate samples collected for moisture-content tests representative of actual stockpile conditions and are samples taken periodically during daily concrete production?
- Are admixtures are prevented from freezing?
- Have adequate provisions been established for producing concrete in hot and cold weather (i.e., provisions for replacing water with ice during hot weather and for heating water during cold weather)?
- Is concrete transporting equipment suitable and in an acceptable condition? Are concrete truck mixers certified to NRMCA standards if any ingredients are added after concrete is transported from batch plant? Are truck drum revolution counters operable and are they retested after each batch is discharged?

- Pre-placement Activities
  - Was concrete reinforcing steel (rebar) and other hardware associated with structural concrete, such as and embedded plates, anchor bolts, purchased from a supplier with an approved QA program?
  - Do records indicate that the physical and chemical testing was performed on supplied hardware and demonstrate it meets the appropriate standards?
  - Are storage conditions for reinforcing steel and embedments adequate to ensure that these materials will not become contaminated with materials such as mud, excessive rust, grease, oil, etc., which could affect the bonding of the rebar and concrete?
  - Are non-conforming or unqualified materials segregated from qualified materials?
  - Are reinforcing steel and embedments, such as anchor bolts, waterstops, and embedded plates, installed in accordance with specifications, codes, drawings, and procedures?
  - Are the number, size and spacing of reinforcing steel bars, bar splices, and embedments in accordance with design drawings and specifications?

- Is installed steel secured and clean (i.e., free from oil, paint, weak dried mortar, dried mud, loose rust, etc.) and does it have proper clearances?
- Do areas where embedded plates with anchors, such as Nelson studs, are to be set in concrete have sufficient concrete to provide bond and are these areas excessively congested with reinforcing steel?
- Is reinforcing steel bending properly performed and controlled?

* Mechanical and Welded Rebar Splices
  - Does the minimum development length of structural steel meet the requirements of drawings and specifications?

    Note: Reinforcing steel is typically spliced by overlapping adjacent bars. The minimum length of the overlap, which is referred to as development length, is shown on the reinforcing steel drawings. In areas where the required development length cannot be obtained, rebar is spliced using either a mechanical connector or welded splice.
  - When mechanical splices are used, have the types of splices been tested, qualified, and approved for use in accordance with manufacturer's instructions? Do the contractor's installation procedures result in an installed configuration that will reflect the laboratory testing conditions?
  - Are crews installing mechanical splices, such as Headed Reinforcement Corporation (HRC) couplers and bar-lock couplers, properly qualified?
  - Are mechanical splices fabricated in accordance with manufacturer's instructions?
  - Is each mechanical splice defined in design documentation by materials used, location, crew, type of splice, and heat number (if applicable)?
  - Is sampling and testing performed at proper frequency and are acceptance criteria defined?

    Note: Rebar splices are qualified by tensile testing. Minimum tensile capacity of splices is 125 percent of yield stress of rebar.
  - Are inspections performed during and after splicing by qualified inspection personnel?
  - Has the process used for welding splices been qualified and is it documented on a written welding procedure specification and on a procedure qualification record?
  - Do welder qualification records, and the results test assembly tensile testing, indicate that welders are properly qualified?
  - Are the locations of welded splices identified on the drawings and do rebar splice weld records identify the welder, process, filler material, and inspection records?
  - Are welds inspected by qualified inspection personnel?
  - Have pre-placement planning and training been completed to ensure good-quality construction and to protect against unplanned construction joints?
  - Are there enough concrete vibrators on hand, with extras on standby, for consolidating concrete?
  - Is there sufficient access available to placement location for vibrator operators, concrete placement equipment, inspection personnel, and other craftsman?
  - Have adequate preparations been made for curing, protection from rain, and hot or cold weather protection before the start of concrete placement activities?
  - Has the placement area been cleaned?

- Is joint preparation specified in the construction specification?
- Are locations of construction joints as shown on the drawings?
- Are forms secure, leak-proof, and free from water, ice, and snow?
- Do records indicate that QC performed a pre-placement inspection before any concrete was placed?

- In-process testing of freshly mixed concrete
  - Is concrete sampled at the proper frequency during placement for determination of temperature, slump (ASTM C143), air content (ASTM C173 or C231), and unit weight?
  - Do sampling and testing techniques conform to the procedures specified in ASTM C172?
  - Are samples for air-entrained, pumped concrete obtained from the end of pump line, at point of placement?
  - Are test specimens (cylinders) for concrete strength testing sampled at the required frequency? Are the cylinders molded, handled, and cured in accordance with specified requirements? Are curing boxes available to properly store and cure cylinders for the first 24 hours (ASTM C-31)?
  - Is the equipment used to perform onsite testing of materials, freshly mixed concrete, and hardened concrete cylinders, calibrated at the required frequency?
  - Are personnel performing sampling and testing trained and qualified?
  - Do concrete testing personnel have authority to reject concrete batches not meeting specification requirements?

- Concrete placement activities
  - Are concrete batch tickets reviewed by QC inspectors to verify proper mix was delivered to placement location?
  - Is the amount of water, if any, withheld from the batch recorded on the batch ticket?

    Note: The quantity of withheld water added, also referred to as retempering water, is determined based on the maximum water-cement ratio.
  - Is the time limit (normally a maximum of 1.5 hours) between mixing and delivery met, and is the total number of revolutions of the truck mixer limited to 300 or less? (ASTM C-94).
  - Is concrete remixed in the truck for a minimum of an additional 30 revolutions of the truck mixer when admixtures or water are added after concrete is discharged from batch plant? (See ASTM C94)
  - Are slump tests performed after addition of admixtures or withheld water and remixing?
  - Is the total volume of admixtures within the concrete mix design and admixture manufacturer's recommendations?
  - Have specification temperature limits been met?
  - Are placement drop distances within specification requirements?
  - Are vibrators approved and are they used properly by trained individuals? Is special attention given to areas of high reinforcing or embedment steel congestion to preclude areas of voids or honeycombing?
  - Are inspections during placement performed as required and by qualified personnel?

- Post-placement Activities
  - Is curing performed in accordance with specifications and procedures with regard to the method, materials, duration, and temperature (concrete and ambient)?
  - Are inspections (during curing and after form removal) performed and documented in QC records?
  - Are defects evident such as voids (honeycomb), cold joints, excessive cracking, delaminations, excessive entrapped air voids (bug holes), or form-related defects such as sand streaking or inadequate bracing?
  - Are concrete placements inspected after form removal to identify any defects in concrete? Have defects been documented and evaluated before acceptance of the placement?
  - Is engineering direction available onsite to monitor structural concrete construction activities? Is the onsite engineering staff involved in disposition of nonconformance reports and in preparation of field change requests for approval by the design-engineering organization?

- Qualifications of QC personnel
  - Have qualifications (education and experience) of testing and inspection personnel been verified by the employing organization. Are personnel qualifications supported by documentation?
  - Do QC inspection personnel know the requirements applicable to their work activities?
  - Is there an adversarial or intimidating relationship between QC inspection and construction craft personnel?
  - Is lack of management support for QC apparent?
  - Is there a sufficient number of adequately qualified QC personnel at the construction site?

- Quality Records
  - Are records produced that document testing frequency and test results?
  - Do the records indicate the actual conditions encountered in the field and provide adequate documentation of work and inspections?
  - Do records include sufficient detail to document:
    - Mix design, location, time placed, water additions, temperature of the concrete mix, and ambient conditions;
    - Concrete strength;
    - Results of inspections;
    - Repairs;
    - Proper installation of rebar; and
    - Curing in accordance with design requirements?
  - Are records legible, complete, reviewed by QC and/or engineering personnel, and readily retrievable?
  - Do receipt inspection records for materials such as cement, concrete aggregate (sand and gravel), concrete admixtures, reinforcing steel, splices, and other components confirm that materials met specification requirements?
  - Do concrete test records indicate specified concrete strength was obtained?
  - Do nonconformance/deviation records include current status of these items?

- Do training and qualification records indicate that craft and QC personnel are adequately qualified to perform their assigned duties?
- Do records of QA audits establish that the required audits were performed and that deficiencies identified during audits were corrected, and that corrective action was such that repetition of the deficiency, or similar deficiencies, would be precluded?

INSPECTION GUIDANCE

Documented safety analyses, construction contracts, and approved Project QA Program specify design, construction, and QA/QC requirements. These requirements are implemented in the construction specifications, drawings, work procedures, and QA implementing procedures.

Subpart 2.5, Quality Assurance Requirements for Installation, Inspection, and Testing of Structural Concrete, Structural Steel, Soils, and Foundations for Nuclear Power Plants, ASME NQA-1 specifies additional QA requirements for structural concrete. The American Concrete Institute "Manual of Concrete Inspection" is also a good reference. However, the project documents, which include specifications, drawings, and procedures, specify and control the construction and inspection processes. QA/QC inspection and construction procedures should be reviewed and compared with the requirements of the applicable codes and construction specifications. QA/QC procedures must provide for effective inspections which will ensure that work is performed in accordance with specification requirements. Laboratory and field-testing procedures must provide for verification of correct material usage and correct selection of reference standards. Qualified personnel should review test results and determine if results are acceptable. Construction procedures must reference the required inspection hold points and must also address the QA/QC department stop-work authority.

Structural concrete construction activities should be observed to ascertain they are consistent with standard industry practices. Look at the dynamics of the work force, the attitudes in work crews, and relations between construction personnel and QA/QC personnel. Determine whether the construction labor forces also perform their own checks of work as it is completed, or if they rely solely on QA/QC. Look at the level (experience, training, and number) of supervision during concrete-placement activities. Look at how the QA/QC inspectors perform their inspection and check-offs. Is it done sequentially as work is being done?

The construction specifications must translate design requirements into details sufficient to define the technical requirements for concrete construction activities. The specifications should provide for control of design changes and the issuance of design change notices. The review of procedures, specifications, and drawings should ensure that concrete construction and inspection activities are controlled and performed in accordance with applicable requirements. QA/QC procedures should specify acceptance-testing requirements and should specify the personnel and interface responsibilities required to define, control, and resolve field problems or design problems that are evidenced during construction. QA/QC procedures must provide for effective inspections that will assure that work is performed in accordance with specification requirements. The procedures should require verification of specified controls and should not be accomplished merely by surveillance. Laboratory and field-testing procedures must provide for verification of correct material usage, correct selection of reference standards, and should prohibit discretionary selection of inspection and testing parameters. Construction procedures must reference the required inspection hold points and must also address the QA department authority to stop work.

Manufacture of Concrete

Qualification of Materials

Chemical and physical tests for all materials used must indicate that specifications have been met. Testing is required to be performed at the required frequencies, e.g., each lot or shipment of cement is tested. Tests results may be provided by the manufacturers via certified materials test reports (CMTRs), or may be performed at an independent testing laboratory. Water used for batching concrete should be tested to demonstrate that the water does not contain impurities such as chlorides which may affect the rebar. If the site water to be used to batch concrete is non-potable, the acceptability of the water is determined as follows: Concrete is batched using the site water and compared to concrete batched using distilled water. In this test, the normally accepted standard is that the site water is deemed acceptable if samples batched from site water do not result in a reduction in strength of more than 10 percent than samples batched using distilled water, provided chemical testing shows that site water does not contain impurities that may be detrimental.

Concrete-Mix Design

A concrete-mix design must be completed for each type/strength of concrete mix to be used in Safety Class structures. The mix design must be completed using the qualified materials, sufficiently in advance of the planned concrete-placement start dates, to demonstrate that the concrete mix will satisfy the job requirements for slump, air entrainment, strength and any other specified parameters. Test cylinders need to be molded, cured, and tested to demonstrate that the required design requirements will be achieved within the specified time period (e.g., 7, 28, or 90 days). It is not an acceptable practice to attempt to base the final concrete design strength on incomplete test results (e.g., estimating the 28-day strength, based on results of test cylinders tested at ages of 7 and 14 days). If the sources of materials used in the concrete are changed, new mix designs need to be qualified, before placement into Safety Class structures.

Concrete Batch Plant

Concrete batch plants providing concrete for use at nuclear facilities must be certified under the NRMCA program. This certification provides evidence that a registered professional engineer has reviewed the facility and has seen evidence that certain necessary capabilities exist to produce quality concrete. Any other batch-plant certification should include the inspection attributes, listed in the NRMCA checklist, which are used to inspect the facility before any recommendation for certification. As part of the certification process, concrete uniformity testing must be performed in accordance with ASTM C-94, at periodic intervals.

Materials need to be properly stored at the batch plant. Non-conforming or unqualified materials are required to be segregated from qualified materials. Storage of cement and admixtures require control so that shelf life is controlled and older materials are used before recently received materials. Cement and flyash are required to be protected from moisture. Generally, cement should be used within 180 days of manufacture. Admixtures must be used within the shelf life specified by the vendor. Admixtures need to be protected from freezing. An adequate supply of all materials needs to be available at the batch plant, to complete the placement, with sufficient reserves of materials to make up for concrete batches that may be rejected because of noncompliance with specification requirements.

The moisture content determination of aggregates is an important test to accurately calculate the total water in each batch of concrete. Fine and coarse-aggregate-moisture-content testing needs to be performed periodically, throughout daily concrete production. Frequency of testing will be determined based on weather conditions and variations in the moisture content.

Trucks used to transport concrete from the batch plant to the job site need to be inspected to ensure that they are clean and free from dirt/debris and/or water which could become mixed with, and contaminate, the concrete. Truck mixers need to be certified in accordance with NRCMA standards. The certification process also requires concrete uniformity testing in accordance with ASTM C-94, at periodic intervals, if mixing of the concrete is performed in the trucks, or water or other ingredients are added to the concrete batch after the concrete is discharged from the batch plant.

<u>Pre-Placement Activities</u>

Concrete reinforcing steel placement should be checked for size, correct number of bars, spacing, splice locations, bending, proper clearances from face of forms or excavated surfaces (i.e., verify rebar will have minimum required cover, in addition to the correct "d" distance), and anchorage. Reinforcing steel needs to be free from oil, grease, paint, loose rust, dried mud, mortar, etc. The steel needs to be firmly held within the forms (usually tie wire is used), to prevent the rebar from being moved during concrete placement. Particular attention needs to be directed to installation of column ties, stirrups, and dowels. Verify that other hardware items to be embedded in the concrete placement are clean, properly located, and firmly anchored.

For mechanical splices, review the mechanical splicing instructions issued by the vendor. This document specifies the proper procedure to be used in mechanical splicing operations. Typical inspection parameters for all types of mechanical splices require cleanliness of the ends of the rebar to be spliced, verification of adequate embedment of the rebar ends, within the splicing sleeve, and verification that the sleeve is centered over the ends of both bars to be spliced. Identification of each splice and the craftsman/crew who completed the splice is also generally required. All craftsmen are required to be trained. All splices require inspection and acceptance by qualified QA/QC inspectors. A testing program will normally be specified to ensure the splices fabricated at the job site meet design requirements.

Requirements for welded splices are specified in the American Welding Society (AWS) Code, AWS D1.4. The requirements for preparation of the ends of the bars, welding process, filler materials, welder qualifications, and inspector qualifications are discussed in detail in the AWS Code.

The area where concrete is to be placed needs to be clean and free of debris. Materials such as sawdust, wood, dried mortar, tie wire, and other debris need to be removed from the forms before placement of concrete. Access ports are usually provided in the forms to permit cleaning and inspection. Water jets and/or compressed air are generally used for cleaning. Forms must be well secured and braced so they will not be displaced by the fresh concrete or concrete-placement activities. The concrete placement rate (permitted rate of rise) needs to be specified, to avoid excessive loads on the forms, caused by hydraulic forces from the fresh concrete. Otherwise, there could be form failures (blow-outs) resulting in injuries to construction personal and/or damage to safety-related structures or components.

Inspection personnel must inspect pre-placements within a time frame that represents the actual conditions before the placement. Quality control pre-placement inspections must not be unnecessarily rushed by advancing concrete work, especially during large placements. When possible, verify the actual as-built condition of reinforcing steel, with respect to the engineering drawings. If deviations exist, verify that proper engineering evaluations have been performed. Records need to document that all pre-placement construction and inspection activities have been completed. Concrete surfaces (joints) on which additional concrete is to be placed should be roughened, and all loose materials removed to ensure good bonding of the new concrete to existing concrete. The joints should be kept damp for a specified period, usually 12 to 24 hours, before concrete placement. There should be no standing water in the forms.

During periods when concrete is to be placed or cold weather is expected during the curing time, provisions must be made to keep the concrete above 40 degrees Fahrenheit, preferably in the range of 50 to 60 degrees Fahrenheit. If concrete is being mixed or transported in weather below 40 degrees Fahrenheit, the ingredients may be pre-warmed so that the temperature of the concrete after placement is elevated to account for losses. Heating the water is the most effective and most easily controlled technique, but the aggregate must not be frozen. The water should not be so hot as to cause "flash set" of the cement during mixing; that is, the temperature of the mortar should not exceed 100 degrees Fahrenheit. If hotter water is required to warm the aggregate, the water and aggregate may be mixed before addition of cement. If the aggregate is heated, close control must be exercised, and the aggregate must be frequently checked for variations in moisture content caused by local variations in heating. Direct fired heaters may produce carbon dioxide, in the exhaust fumes, forming calcium carbonate on the surface of fresh concrete. Also, use of chemicals should not be permitted to accelerate the concrete set times in cold weather.

Where the ambient temperature rises much above 70 degrees Fahrenheit, consideration must be given to the effect of high temperatures on the concrete. Although concrete <u>cured</u> at temperatures up to 100 degrees Fahrenheit gives higher early strength, with little degradation of long-term strength, high temperatures during mixing, transportation, and placement can be seriously detrimental. The most obvious effect is that the concrete requires more water for work ability or the use of additives. A less obvious effect is the need for special attention to curing, because the higher temperature increases water evaporation from the concrete.

Exposure to strong summer sun can raise the temperature of ingredients, equipment, forms, etc., far above the air temperature. If this occurs, provisions should be made for appropriate shades or screens, and the equipment, forms, and metallic embedments, etc., should be wetted just before concrete placement. When ambient temperature is high enough so that the bulk temperature of freshly mixed concrete may exceed specification limits, methods of cooling the ingredients, such as chilling the water, using ice, or using liquid nitrogen must be used. If ice is used, it must be crushed or flaked so that all the ice is melted by the time mixing is completed.

In addition to having adequate equipment available to complete the concrete placement, extra equipment, such as vibrators, concrete trucks, and concrete pumps need to be available. Enough personnel need to be available, to fill in and to keep concrete placement personnel from becoming fatigued by long work hours, which could lead to errors and substandard construction. Necessary equipment needs to be available to form construction joints on short notice, in case of an unforeseen stoppage of the concrete placement. Equipment needs to be available to protect the new concrete from all weather conditions, including rain, heat and cold.

Concrete Placement Activities

The practice of withholding water at the batch plant and then tempering at the point of placement should take into account the results of air content and slump measurements taken at the point of placement. Efficient radio communications between the batch plant and field QC testing personnel will minimize the need for water tempering at the point of placement and thus result in more uniform batching. Check time (90 minutes max) of concrete receipt for truck transported, centrally mixed concrete, and number of truck-mixer revolutions (300 max). Also, verify the amount (quantity should be documented) of water added, if permitted, and mixing (minimum 30 revolutions).

Concrete should not strike forms or bounce against reinforcing bars causing segregation of aggregates from the mix. There should be a sufficient number of vibrator operators and, preferably, some spare vibrators that should be checked for proper operation, before starting to place concrete. Proper vibrator operation involves duration of vibration, distance between vibrator insertions, and depth of insertions. The vibrators should be handled and operated vertically and never "cast" away from the operator horizontally and then retrieved. Concrete should be placed horizontally, in about 12 inch layers, and never allowed to pile much higher in one area of the form than another. The vibrator should penetrate through the new concrete well into the previously placed layer, to avoid any "layer-cake" effect. Occasional contact of a vibrator with the forms is permissible, and with the reinforcement is desirable. Care should be taken that reinforcement is not displaced by vibrators, or by people walking on the steel. Vibrators should not be used to move concrete laterally. Any excess water in the forms should be removed and not permitted to mix with the concrete.

Post-Placement Activities

The concrete needs to be protected from damage and properly cured. Proper curing requires keeping the surface of the concrete moist and, in cold weather, warm so that hydration of the cement continues until the concrete achieves design strength. Curing can be accomplished using moisture (water sprays, etc.) or by use of a curing compound. However, curing compounds should not be used on construction joints unless the curing compound is removed prior to the next placement. Curing compounds used on construction joints may act as a bond breaker and result in successive placements not achieving good bond. Minimum curing times should be specified in the construction records. Formation of ice (freezing of the curing water) on surfaces of the concrete during the curing period should not be permitted. Forms need to remain in place for the period specified in the procedures. The time to remove the concrete forms is often based on achieving a minimum concrete strength.

Defective areas in concrete should be repaired as soon as possible after the forms are removed. Design engineering approval should be obtained for all concrete repair methods. It is not acceptable to repair concrete defects by merely plastering over them with mortar. Concrete defects need to be cut to a depth to expose sound concrete and filled with concrete of the same strength as that in the structure. Repair of defects are usually classified as cosmetic if they are shallow surface defects, and structural if they extend to a depth below the outer layer of rebar. Locations of concrete defects and repair methods need to be documented in licensee inspection records. Note that areas repaired are required to be protected from the elements and cured to achieve adequate design strength.

Final inspection, evaluation, and acceptance are being controlled and accomplished in accordance with QA/QC requirements. Final inspection procedures should include verifying embed locations and identification of any defects and required repairs. Review the results of compressive strength determinations. Verify that results are being evaluated in accordance with ACI 214, "Recommended Practice for Evaluation of Compression Test Results of Field Concrete". During this portion of the inspection, also review the results of strength tests on mechanical reinforcing steel splices.

Records should be verified to show that mix specified was delivered and placed. Structural drawings or specifications will indicate the design concrete strength. Evaluate trending analysis of nonconforming items and determine if generic items are being identified and corrected.

Particular attention should be directed toward the qualification of personnel and their work performance. In the past, at some projects, there was a tendency for some organizations to hire untrained personnel residing near the site who had no prior work experience in concrete materials testing or inspection, train them, and certify them. Although the individuals were trained and certified, in some instances, inexperience of personnel and the lack of depth of knowledge was found to be detrimental to an effective QA/QC program. Changing of personnel between different jobs and turnover of personnel can also result in problems.

In determining the adequacy of QA/QC staffing, the effectiveness of their activities must be considered. Insufficient or unqualified personnel, or inadequate management, may result in inadequate inspections of concrete-construction activities. Capabilities and effectiveness, rather than only the number of personnel, are the principal criteria to be used.

Prevalent Errors and Recent Concerns

This section is included to provide background for inspectors on past structural concrete construction problems that have been identified and on certain areas that should be more closely scrutinized.
(Note - These are not listed in order of their perceived importance to safety.)

- Inadequate QA/QC records documenting concrete work activities.
- Improper use of vibrators.
- Exceeding allowable time to place concrete.
- Improper sampling of aggregates.
- Improper curing and/or testing of concrete test cylinders.
- Exceeding allowable concrete temperatures.
- Materials improperly certified.
- Concrete cylinder compression test records exceed allowable coefficient of variation.
- Improper reinforcing steel splicing practices.
- Inadequate concrete curing.
- Samples of concrete not taken where and when required.
- Excessive doses of concrete admixtures.
- Inadequate cleanliness of placement.
- Omission of reinforcing steel, incorrect spacing of reinforcing steel, and/or improper anchorage (failure to firmly tie the rebar) of the steel.
- QC inspections not done conscientiously.
- Excessive drop of concrete.
- Batch plants improperly qualified.
- Improper repair of concrete defects.
- Intentional violation of work procedures by craft personnel to avoid rejection of their work, or to simplify their work. Examples included melting of tie wire into ends of completed cadwelds, unauthorized addition of water to concrete, and covering concrete defects (honeycomb) with mortar to prevent detection by QA/QC inspectors.
- Construction personnel and supervision intimidation of QA/QC inspectors.

REFERENCES

Code of Federal Regulations 10 CFR 830.122, Quality Assurance Criteria for DOE Facilities.

American Concrete Institute (ACI)

ACI 116, Cement and Concrete Terminology.

ACI 117, Standard Specification for Tolerances for Concrete Construction and Materials

ACI 211.1, Recommended Practice for Selecting Proportions for Normal and Heavyweight Concrete.

ACI 212.1, Admixtures for Concrete.

ACI 212.2, Guide for Use of Admixtures in Concrete.

ACI 212.4, Guide for Use of High-Range Water-Reducing Admixtures (Superplasticizers) in Concrete.

ACI 214, Evaluation of Strength Test Results of Concrete.

ACI 221, Guide for Use of Normal Weight and Heavyweight Aggregates in Concrete.

ACI 301, Specifications for Structural Concrete.

ACI 304, Guide for Measuring, Mixing, and Placing Concrete.

ACI 304.2, Placing Concrete by Pumping Methods.

ACI 305, Hot Weather Concreting.

ACI 306, Cold Weather Concreting.

ACI 308, Guide to Curing Concrete.

ACI 309, Guide for Consolidation of Concrete.

ACI 311, Recommended Practice for Concrete Inspection.

ACI 311.1, ACI Manual of Concrete Inspection.

ACI 311.4, Guide for Concrete Inspection

ACI 311.5, Guide for Concrete Plant Inspection and Testing of Ready Mixed Concrete.

ACI 315, Details and Detailing of Concrete Reinforcement.

ACI 318, Building Code Requirements for Structural Concrete.

ACI 347, Guide to Formwork for Concrete

ACI 349, Code Requirements for Nuclear Safety-Related Concrete Structures.

ACI 359, Code for Concrete Reactor Vessels and Containments, Section III, Division 2

ACI 503, Use of Epoxy Compounds With Concrete

ACI 503.4, Standard Specification for Repairing Concrete With Epoxy Mortar

ACI 504, Guide to Sealing Joint in Concrete Structures.

ACI 530-02, Building Code Requirements for Concrete Masonry Structures.

American Society of Mechanical Engineers (ASME)

ASME NQA-1, Quality Assurance Requirements for Nuclear Facility Applications.

American Welding Society (AWS)

AWS D1.1, Structural Welding Code.

AWS D1.4, Structural Welding Code - Reinforcing Steel

American Society for Testing and Materials

ASTM A-615, Deformed Billet-Steel Bars for Concrete Reinforcement.

ASTM A-706, Standard Specification for Low-Alloy Steel Deformed Bars for Concrete Reinforcement.

ASTM C-29, Test for Unit Weight of Aggregate.

ASTM C-31, Making and Curing Concrete Compressive and Flexural Strength Test Specimens in the Field.

ASTM C-33, Standard Specification for Concrete Aggregates.

ASTM C-39, Test for Compressive Strength of Molded Concrete Cylinders.

ASTM C-94, Standard Specification for Ready Mixed Concrete.

ASTM C-109, Standard Method of Test for Compressive Strength of Hydraulic Cement Mortar (Using 2-in. Cube Specimen).

ASTM C-117, Test for Materials Finer Than No. 200 Sieve in Mineral Aggregates by Washing.

ASTM C-127, Test for Specific Gravity and Absorption of Coarse Aggregate.

ASTM C-128, Test for Specific Gravity and Absorption of Fine Aggregate.

ASTM C-136, Test for Sieve or Screen Analysis of Fine and Coarse Aggregates

ASTM C-143, Test for Slump of Portland Cement Concrete.

ASTM C-150, Specification for Portland Cement.

ASTM C-171, Specification for Sheet Materials for Curing Concrete.

ASTM C-172, Sampling Fresh Concrete.

ASTM C-173, Test for Air Content of Freshly Mixed Concrete by the Volumetric Method.

ASTM C-192, Making and Curing Concrete Test Specimens in the Laboratory.

ASTM C-231, Test for Air Content of Freshly Mixed Concrete by the Pressure Method.

ASTM C-260, Standard Specifications for Air Entraining Admixtures for Concrete

ASTM C-309, Specification for Liquid Membrane - Forming Compounds for Curing Concrete

ASTM C-494, Standard Specification for Chemical Admixture for Concrete

ASTM C-566, Standard Method of Test for Total Moisture Content of Aggregate by Drying

ASTM C-642, Test for Specific Gravity, Absorption, and Voids in Hardened Concrete.

ASTM D-512, Test for Chloride Ion in Industrial Water and Industrial Waste Water

ASTM D-1888, Tests for Particulate and Dissolved Matter in Water.

U. S. Army Corps of Engineers, Handbook for Concrete and Cement, Published by US Army Corps of Engineers Waterways Experiment Station, Vicksburg, Miss.

NRC Publications

U.S. Nuclear Regulatory Commission, Regulatory Guide 1.94, Quality Assurance Requirements for Installation, Inspection, and Testing of Structural Concrete and Structural Steel During the Construction Phase of Nuclear Power Plants.

U.S. Nuclear Regulatory Commission, Regulatory Guide 1.136, Materials, Construction, and Testing of Concrete Containments.

U.S. Nuclear Regulatory Commission, Regulatory Guide 1.142, Safety-Related Concrete Structures for Nuclear Power Plants (Other Than Reactor Vessels and Containments).

U.S. Nuclear Regulatory Commission, Regulatory Guide 1.199, Anchoring Components and Structural Supports in Concrete.

National Ready Mixed Concrete Association (NRMCA)

NRMCA, Concrete Plant Standards of the Concrete Plant Manufacturers Bureau

NRMCA, Truck Mixer and Agitator Standards of the Truck Mixer Manufacturers Bureau

Others

Concrete Reinforcing Steel Institute, Manual of Standard Practice

Concrete Manual, published by the Bureau of Reclamation.

Publications of the Portland Cement Association.

For information and standards for studs (proprietary name: Nelson Studs), which are used to secure embedded item such as pipe sleeves and plates, to concrete structures, refer to Chapter 8, Stud Welding, Volume 2 of Welding Handbook, published by the American Welding Society.