	EA Enterprise Assessments	Number: EA CRAD 31-17 Revision: Rev. 1 Effective Date: October 24, 2019
Nuclear Facility Construction Structural Concrete Criteria and Review Approach Document		
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1.0 PURPOSE

The mission of the U.S. Department of Energy (DOE) Office of Environment, Safety and Health Assessments (EA-30) is to assess the effectiveness of safety and emergency management systems and practices used by line and contractor organizations and to provide clear, concise, rigorous, and independent evaluation reports of performance in protecting workers, the public, and the environment from the hazards associated with DOE activities.

In addition to the general independent oversight requirements and responsibilities specified in DOE Order 227.1, *Independent Oversight Program*, this criteria review and approach document (CRAD), in part, fulfills the responsibility assigned to EA in DOE Policy 226.1B, *Department of Energy Oversight Policy* to conduct independent oversight of contractor implementation of DOE Order 226.1B, *Implementation of Department of Energy Oversight Policy*, Attachment 1, Contractor Requirements Document.

The CRADs are available to DOE line and contractor assessment personnel to aid them in developing effective DOE oversight, contractor self-assessment, and corrective action processes. The current revision of EA's CRADs are available at http://www.energy.gov/ea/criteria-and-review-approach-documents.

2.0 APPLICABILITY

The following CRAD is approved for use by the Office of Nuclear Safety and Environmental Assessments (EA-31) at DOE Hazard Category 1, 2, and 3 facilities.

3.0 FEEDBACK

Comments and suggestions for improvements on this CRAD can be directed to the Director, Office of Environment, Safety and Health Assessments.

4.0 CRITERIA REVIEW AND APPROACH

The review focuses on the implementation of construction activities for structural concrete, including pre-placement work and inspections, manufacture (batching) of concrete, concrete placement, post-placement inspections, and review of records. The review will evaluate the effectiveness of contractor programs and processes for production, placement and inspection of concrete meeting structural design requirements. The following objectives provide a set of criteria and suggested lines of inquiry to assess structural concrete construction activities. The structures may or may not be identified as safety class structures. The objectives of this CRAD are stand-alone sections to be used in any combination based on the specific assessment and the work in progress at the time of the assessment.

OBJECTIVES

SC.1: Applicable DOE directives and industry standards are referenced in design basis documents and contract specifications. Project documents, including specifications, drawings and procedures, specify and control the construction and inspection processes.

Criteria:

1. 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 414.1D, *Quality Assurance,* and DOE Order 226.1A, *Implementation of DOE Oversight Policy,* other DOE Orders specified in the Contractor Requirements Documents (CRD) incorporated in the contract, and other requirements specified in the Building Code CRD which may include Subparts listed in NQA-1, Part II, and NQA-1, Part III.

2. The construction of safety-related concrete structures for nuclear facilities meets the requirements of American Concrete Institute (ACI) standard ACI 349, *Code Requirements for Nuclear Safety Related Concrete Structures*, or ACI 318, *Building Code Requirements for Structural Concrete*, and other applicable ACI Codes referenced in the CRD.

3. The construction specifications 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. (10 CFR 830.122(d))

4. Procedures, specifications, and drawings should ensure that concrete construction and inspection activities are controlled and performed in accordance with applicable requirements. (10 CFR 830.122(d))

5. Construction procedures must reference the required inspection hold points and must also address the Quality Assurance (QA) department authority to stop work. (NQA-1, *Quality Assurance Requirements for Nuclear Facility Applications,* requirements, or applicable standard referenced in the CRD)

6. 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. (10 CFR 830.122(h))

SC.2: Concrete for nuclear safety related structures is batched in a certified concrete plant using materials meeting American Concrete Institute (ACI) and American Society for Testing and Materials (ASTM) standards blended in proportions determined in a laboratory controlled concrete mix design.

Criteria

1. The concrete production sub-contractor has established and implemented a Quality assurance program in accordance with 10 CFR 830, Subpart A, *Quality Assurance Requirements,* and ASME NQA-1, *Quality Assurance Requirements for Nuclear Facilities Applications,* or the sub-contractor is following the QA program established by the project's General Contractor.

2. The concrete batch plant has been inspected and certified in accordance with National Ready Mixed Concrete Association (NRMCA) Standards.

3. The materials (cement, fine and coarse aggregate, water, and admixtures) used in batching of concrete are tested in accordance with ASTM or other approved Standards to verify the materials meet design specification requirements. (ACI-349, *Code Requirements for Nuclear Safety Related Concrete Structures,* or applicable Codes/Standards referenced in the CRD)

4. Materials used to produce concrete are measured and proportioned in the quantities determined through controlled laboratory mix designs that were completed to establish that the concrete mix would produce concrete with the properties required by the design criteria. (ACI-349, *Code Requirements for Nuclear Safety Related Concrete Structures,* or applicable Codes/Standards referenced in the CRD)

5. Self-Consolidating concrete (SCC) mix designs are tested using standardized test methods specifically developed for testing SCC, and personnel performing these tests have been trained and certified to correctly perform the quality control tests specifically developed for SCC. These include: ASTM C1610, *Standard Test Method for Static Segregation of Self-Consolidating Concrete Using Column Method*; ASTM C1611, *Standard Test Method for Slump Flow of Self-Consolidating Concrete*; ASTM C1621, *Standard Test Method for Passing Ability of Self-Consolidating Concrete by J-ring*; ASTM C1712, *Standard Test Method for Rapid Assessment of Static Segregation*

Resistance of Self-Consolidating Concrete Using Penetration Test; ASTM C1758, *Standard Test Method for Fabrication of a Test Specimen with Self-Consolidating Concrete*.

Additional Considerations

- Do contractor procurement specifications require that concrete ingredients meet applicable industry standards?
- Are concrete ingredients tested in accordance with American Society for Testing and Materials (ASTM) methods: ASTM C150 for cement, ASTM C618 for fly ash, ASTM C33 for aggregate, and ASTM C260, C494, and/or C1017 for chemical additives (concrete admixture)
- Is the water used for concrete tested? An acceptable test method for water is detailed in the U.S. Army Corps of Engineers Handbook of Concrete and Cement, Test Methods CRC 440-63 and 406-79, or ASTM C1602, Standard Specification for Mixing Water Used in Production of Hydraulic Cement Concrete. Do material test results and vendor certifications indicate that applicable specifications were met?
- Are samples of each concrete mix tested to verify chlorides content in each mix do not exceed recommended limits specified in ACI specifications?
- Is storage of concrete ingredients controlled so that each ingredient can be traceable to an approved source?
- Are cement and fly ash stored in facilities so that they are protected from moisture and contamination from dust, debris, or other materials?
- 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 guidance specified in ACI 237R07, *Self-Consolidating Concrete (Reapproved 2019),* being implemented for designing SCC mixes and demonstrating SCC can be placed without segregation by use of a mock-up with form geometry, reinforcing steel spacing and other embeds similar to areas where placement of SCC is proposed?
- Are admixtures used within the shelf life specified by the vendor?
- 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 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 concrete 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 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 reset (zeroed) after each batch is discharged?

SC.3: Preparations for placement of concrete is planned and implemented to ensure the concrete structure will be constructed in accordance with design requirements. Pre-placement activities include installation of reinforcing steel and other hardware items shown on the design drawings, installation of forms, removing debris from forms prior to placement of concrete, training of concrete placement crews, preparing equipment, and preparing for adverse weather conditions.

Criteria

1. Concrete reinforcing steel is installed in accordance with design and reinforcing steel fabrication drawings. (10 CFR 830.122(f))

2. Forms are leak tight and surfaces where concrete is to be placed are cleaned to remove dirt and debris. Forms shall be properly secured to maintain their position during concrete placement. ACI 347, *Guide to Formwork for Concrete,* provides construction recommendations. (ACI-349, *Code Requirements for Nuclear Safety Related Concrete Structures,* or applicable Codes/Standards referenced in contract documents)

3. Adequate lighting and equipment, such as concrete vibrators, are available, and access for the workers to the concrete placement areas is provided by safe walkways and scaffolding constructed in accordance with DOE Safety Regulations. (10 CFR 830.122(e))

4. Preparations have been completed to protect concrete during inclement weather, such as availability of tarps to protect freshly placed concrete from rain, and availability of heaters and enclosures to prevent freshly placed concrete from freezing. (ACI-349, *Code Requirements for Nuclear Safety Related Concrete Structures,* or applicable Codes/Standards referenced in contract documents)

5. Inspections are completed by craft supervisors, field engineers, and Quality Control (QC) inspectors, as applicable, prior to placement of concrete to verify pre-placement activities (e.g., installation of rebar, cleaning out of forms, etc.) required by design documents have been completed.

6. Inspections are completed prior to placement of concrete slabs to verify specification requirements of all structural fill, undisturbed soil, and rock surfaces that will be in contact with structural concrete. (ACI-349, *Code Requirements for Nuclear Safety Related Concrete Structures,* or applicable Codes/Standards referenced in contract documents)

<u>Additional Considerations</u>

- Was concrete reinforcing steel (rebar) and other hardware associated with structural concrete, such as 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 rebar and other hardware, demonstrating compliance with specification requirements?
- Are storage conditions for reinforcing steel and embedments adequate to ensure that these materials will not become contaminated with 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, (anchor bolts, waterstops, and embedded plates, etc.) 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 not excessively congested with reinforcing steel so concrete can flow freely?
- Is reinforcing steel bending properly performed and controlled
- Does the minimum development length of reinforcing 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 rebar welding been qualified and is it documented on a written welding procedure specification and on a procedure qualification record?
- Do welder qualification records demonstrate that welders are properly qualified?
- Are the locations of rebar welds identified on the drawings and do rebar weld records identify the welder, process, filler material, and inspection records?
- Are rebar 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?
- Are construction joint locations shown on the drawings and is joint preparation specified in the construction specification?
- Are forms secure, leak-proof, and free from water, ice, snow, dirt and debris?

- Do construction procedures include a hold point that requires QC inspectors to perform pre-placement inspection before any concrete is placed?
- Have inspections and field testing been completed in accordance with specifications for all structural fill, undisturbed soil, and rock surfaces that will be in contact with structural concrete to verify surface cleanness, removal of rock and free water, correct contour, and specified sub-grade condition?

SC.4: In-process testing of freshly mixed concrete is performed in accordance with ASTM Standards by qualified personnel using calibrated equipment.

Criteria

1. The concrete production sub-contractor has established and implemented a Quality assurance programs in accordance with 10CFR 830, Subpart A, *Quality Assurance Requirements,* and ASME NQA-1, *Quality Assurance Requirements for Nuclear Facilities Applications,* or the sub-contractor is following the QA program established by the project's General Contractor.

2. Adequate equipment used to test freshly mixed concrete (slump cones, tape measures, air meters scales thermometers) is available. Equipment is in good condition and calibrated in accordance with NQA-1 requirements. (10 CFR 830.122 (h))

3. A sufficient number of trained, experienced, and certified test personnel (QC inspectors) are available to perform testing of the freshly mixed concrete within the time limits specified in ACI and ASTM Standards. (10 CFR 830.122(b))

4. Personnel performing concrete inspections are qualified in accordance with ASTM E329, *Standard Specification for Agencies Engaged in Construction Inspection, Testing, or Special Inspection,* and ACI 301, *Specifications for Structural Concrete.*

5. Results of the in-process test results are promptly evaluated and communicated to the concrete batch plant. Concrete not meeting specification requirements is rejected. (ACI-349, *Code Requirements for Nuclear Safety Related Concrete Structures,* or applicable Codes/Standards referenced in contract documents)

Additional Considerations

- Is concrete sampled at the proper frequency during placement for determination of temperature, slump (ASTM C143), and unit weight? When specified, is air content, (ASTM C173 or C231), tested at the frequency stated in the concrete specification?
- Do concrete sampling techniques conform to the standards 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?
- If SCC is being placed on the project, have personnel performing testing of the SCC been trained and certified or qualified to test SCC?

- Do concrete testing personnel have authority to reject concrete batches not meeting specification requirements?

SC.5: Concrete is placed by trained personnel. Placement and consolidation of concrete is continuously inspected to ensure work is performed in accordance with ACI recommended practices.

Criteria

1. Concrete placement crews are trained. A sufficient number of personnel are available to accomplish the work. (10 CFR 830.122(b))

2. Concrete placements are perform in accordance with ACI recommendations regarding consolidation of concrete, prohibiting lateral movements of concrete using vibrators, and controlling rate of rise in forms. (ACI-349, *Code Requirements for Nuclear Safety Related Concrete Structures,* or applicable Codes/Standards referenced in contract documents)

3. Concrete placement operations require continuous inspection by QC personnel to ensure the mix delivered to the point of placement meets specification requirements, and to ensure placement of concrete into the forms and concrete consolidation is performed in a manner consistent with ACI recommendations (ACI-349, *Code Requirements for Nuclear Safety Related Concrete Structures,* or applicable Codes/Standards referenced in contract documents)

<u>Additional Considerations</u>

- 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 re-tempering 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 C-94)
- 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?
- If SCC is being placed on the project, have concrete placement crews been trained to properly handle and place the SCC? NOTE: SCC requires little or no vibration.
- Are inspections during placement performed as required and by qualified personnel?

SC.6: After placement of concrete is completed, protection of the concrete during curing, examination of concrete surfaces after form removal and repairs to concrete defects are performed following ACI recommended practices. QC inspections of these activities are performed and documented in QC records.

Criteria

1. Concrete is properly cured for the period cited in the design specifications. (10 CFR 830.122(e))

2. Post placement inspections of concrete surfaces after forms have been removed are performed by trained personnel and documented in QC records. (ACI-349, *Code Requirements for Nuclear Safety Related Concrete Structures,* or applicable Codes/Standards referenced in contract documents)

3. Defects in concrete placements are repaired in accordance with design specification, following recommendations in the design documents and ACI Standards. (10 CFR 830.122(c))

Additional Considerations

- 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, delamination's, 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?

SC.7: Results of concrete strength tests are evaluated to verify in-place concrete meets design requirement.

Criteria

1. Test specimens (concrete cylinders) are handled, cured, and tested in accordance with ACI recommended practices and ASTM Standards. (ACI-349, *Code Requirements for Nuclear Safety Related Concrete Structures,* or applicable Codes/Standards referenced in contract documents)

2. Results of tests (unconfined compressions tests) performed on the concrete cylinders are evaluated by qualified personnel per ACI 214, *Guide to Evaluation of Strength Test Results of Concrete,* to determine if in-place concrete strength meets design requirements. (ACI-349, *Code Requirements for Nuclear Safety Related Concrete Structures,* or applicable Codes/Standards referenced in contract documents)

3. In the event the concrete test data indicates concrete strength has not attained the design strength required by design criteria, steps shall be taken to assure the structure will still meet its design requirement. This may include additional testing or an engineering evaluation to determined

corrective actions. (ACI-349, *Code Requirements for Nuclear Safety Related Concrete Structures,* or applicable Codes/Standards referenced in contract documents)

Additional Considerations

- Were concrete cylinders maintained in a controlled environment in accordance with ASTM C-39 for the specified time between casting the cylinders and testing?
- Are the concrete cylinders tested by qualified personnel, using unconfined compression test equipment that has been calibrated as recommended by national standards?
- Were the test results evaluated and documented in permanent quality records?
- When test results showed indications that in-place concrete had not attained design strength, that is, indication that in-place concrete strength is lower than the minimum specified in the design documents, have immediate corrective actions been initiated to perform engineering evaluations to determine the cause and necessary corrective actions, and concrete operations suspended until corrective actions are implemented?

SC.8: QC Personnel are trained and qualified in accordance with NQA-1 requirements and certified to perform concrete inspections. Construction management has policies in place to prevent intimidation or harassment of QC inspectors.

Criteria

1. Qualifications of personnel performing QC inspections of concrete work activities comply with NQA-1, *Quality Assurance Requirements for Nuclear Facility Applications,* requirements, or applicable Codes/Standards referenced in the CRD, regarding experience, training, and certification. QC inspectors demonstrate adequate knowledge of the requirements of their work activities. (DOE O 414.1D)

2. Records are to be maintained documenting training, including the results of practical and written exams that demonstrate ability to perform testing and knowledge of QC and construction procedures, and specification requirements. (10 CFR 830.122(d))

3. Construction management supports the QC inspection staff by implementing policies that prevent harassment or intimidation of QC inspectors.

4. The number of qualified QC personnel at the construction site should be commensurate with the work in progress.

5. QC inspectors shall be independent of the performance of work being evaluated.

Additional Considerations

- Is there an adversarial or intimidating relationship between QC inspection and construction craft personnel?
- Does construction management support QC inspectors, and act to prevent any intimidation of QC inspectors by craft or construction supervisors?

SC.9: Quality Records documenting concrete construction work activities are maintained in accordance with NQA-1 and DOE Quality Assurance regulations.

Criteria

1. Records documenting production, placement, and inspection of concrete work are required to comply with NQA-1 requirements, or applicable Codes/Standards referenced in contract documents. (DOE O 414.1D)

2. Records are required to be complete, legible and retrievable. (10 CFR 830.122(d))

Additional Considerations

- 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 and test 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, or if not, the results of evaluations of low strengths and corrective actions?
- 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?

REVIEW APPROACH

Record Review:

- Safety basis documents.
- Design specifications for concrete, structural design drawings, and other design documents that pertain to concrete work.
- Construction procedures related to concrete construction work activities (Installation of reinforcing steel, concrete production, concrete placement, etc.)
- Procurement specifications for reinforcing steel, materials used to produce concrete, and other materials associated with concrete construction work.
- QC inspector and laboratory testing personnel training and certification records.

- Records documenting testing performed to demonstrate concrete materials comply with project quality requirements.
- Results of in-process tests (slump, temperature, unit weight) performed on concrete placed to date.
- A sample of concrete batch tickets from completed placements.
- Concrete mix designs.
- Unconfined compression test data for previously placed concrete.
- Records of deficiencies, non-conformance reports, problems, engineering issues, and corrective actions associated with concrete construction work activities.
- Self-assessments, independent assessments, causal analyses, corrective action plans, and lesson-learned documents related to concrete construction and inspection work activities.

Interviews:

- Field Engineers associated with concrete construction activities
- Construction Management
- Civil QC Inspectors Concrete and materials site laboratory technicians and inspectors
- Batch plant operator and manager
- QA personnel
- Federal Oversight Personnel

Observations:

- Perform a walk down of the batch plant to examine storage of concrete materials, operating equipment, and the systems/controls for documenting concrete production.
- Walk-through the concrete and materials site laboratory to examine laboratory equipment, verify equipment is calibrated, and review records.
- Examine completed concrete placements.
- Examine preparations for the next concrete placement.
- Observe an in-process placement, if one is scheduled during the assessment.

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

<u>Qualification of Materials</u>

Chemical and physical tests for all materials used in production of concrete are necessary to verify that the materials meet specification requirements. 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 is required to 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.

Self-Consolidating Concrete (SCC)

SCC, also referred to as self-compacting concrete, is a highly flowable, non-segregating concrete that can spread under its own weight and fill formwork and flow through and bond to congested reinforcing steel, with little or no vibration. ACI 237R(07), Self-Consolidating Concrete (Reapproved 2019), provides recommendations and guidance on selecting proportions of materials for SCC mixes, placement techniques, employee training, and quality control. Five ASTM test methods, ASTM C1610, C1611, C1621, C1712, and C1758, have been recently developed specifically for measuring the properties of freshly mixed SCC. Personnel performing these tests should be trained to ensure they can correctly perform the tests. ACI and other organizations offer programs to train and certify technicians in SCC testing. The SCC mix should be pre-qualified using mock-ups constructed to duplicate project conditions (form geometry, rebar spacing, etc.). The mock-up demonstration should ensure the SCC mix can flow into formwork and through complex reinforcing steel configurations to produce hardened homogenous concrete without segregation. Other considerations include formwork design, rate of pour, and training of the concrete placement crews. Excessive vibration may result in segregation of SCC mixes.

Concrete Batch Plant

Concrete batch plants providing concrete for nuclear facilities are required to be certified under the NRMCA program. This certification provides evidence that a registered professional engineer has inspected the facility and has determined that the batch plant is capable of producing quality concrete. The batch-plant certification program should include the inspection attributes listed in the NRMCA checklist, for inspecting the batch plant 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 requires control of the shelf life so that older materials are used before recently received materials. Cement and fly ash 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 and 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.

Pre-Placement Activities

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. Each splice and the craftsman/crew who completed the splice is also generally required to be identified. 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 batched and placed in cold weather, 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 hot 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 cured 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 to 18 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. During periods when 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. 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, *Guide to Evaluation of Strength Test Results of 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.

Qualification of QC Personnel

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.

ACRONYMS

ACI	American Concrete Institute
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials, International
AWS	American Welding Society
CMTR	Certified Material Test Report
CRAD	Criteria, Review, and Approach Document
DOE	U.S. Department of Energy
EA	Office of Enterprise Assessments
NRMCA	National Ready Mixed Concrete Association
NQA	Nuclear Quality Assurance
QA	Quality Assurance
QC	Quality Control
SCC	Self-Consolidating Concrete
SSCs	Structures, Systems, and Components

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 214, Guide to Evaluation of Strength Test Results of Concrete

ACI 237, Self-Consolidating Concrete (Reapproved 2019).

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, Guide to Hot Weather Concreting

ACI 306, Guide to Cold Weather Concreting

ACI 308, Standard Practice for 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 318, Building Code Requirements for Structural Concrete

ACI 347, Guide to Formwork for Concrete

ACI 349, Code Requirements for Nuclear Safety-Related Concrete 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 C31, Standard Practice for Making and Curing Concrete Test Specimens in the Field

ASTM C33, Standard Specification for Concrete Aggregates

ASTM C39, Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens

ASTM C94, Standard Specification for Ready Mixed Concrete

ASTM C143, Standard Test Method for Slump of Hydraulic-Cement Concrete

ASTM C150, Standard Specification for Portland Cement

ASTM C172, Standard Practice for Sampling Fresh Concrete

ASTM C173, Standard Test Method for Air Content of Freshly Mixed Concrete by the Volumetric in Method

ASTM C231, Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure in Method

ASTM C260, Standard Specifications for Air Entraining Admixtures for Concrete

ASTM C494, Standard Specification for Chemical Admixtures for Concrete

ASTM C566, Standard Test Method for Evaporable Moisture Content of Aggregate by Drying

ASTM C618, Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete

ASTM C1017, Standard Specification for Chemical Admixtures for Use in Producing Flowing Concrete

ASTM C1602,   Standard Specification for Mixing water Used in Production of Hydraulic Cement Concrete

ASTM C1610,   Standard Test Method for Static Segregation of Self-Consolidating Concrete Using Column Method

ASTM C1611,   Standard Test Method for Slump Flow of Self-Consolidating Concrete

ASTM C1621   Standard Test Method for Passing Ability of Self-Consolidating Concrete by J-ring

ASTM C1712   Standard Test Method for Rapid Assessment of Static Segregation Resistance of Self-Consolidating Concrete Using Penetration Test

ASTM C1758   Standard Test Method for Fabrication of a Test Specimen with Self-Consolidating Concrete.

ASTM E329,   Standard Specification for Agencies Engaged in Construction Inspection, Testing, or Special Inspection

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

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

Other

Concrete Reinforcing Steel Institute, Manual of Standard Practice