Chapter 7
Quality Control and Quality Assurance in RCC Construction

7-1. Quality RCC

a. General. Construction quality management policy and guidance are provided in ER 1180-1-6, "Construction Quality Management," and identify the requirements and procedures for Contractor Quality Control (CQC) and Government Quality Assurance (GQA). The contractor is responsible for the management, control, and documentation of activities that are necessary for compliance with all contract requirements. The government program is responsible for ensuring that contract documents establish performance periods and quality control requirements and for ensuring that the CQC program is functioning as required. Contracting Officers are responsible for ensuring that RCC material quality and workmanship quality are clearly defined, that the construction contractors meet the operational requirements, and that the final RCC structure meets the design requirements. The common goal of obtaining quality construction for RCC should be developed between the construction contractor and the government. Clear objectives shall be established within this working relationship that accomplish the end product quality required by the contract documents.

b. GQA program. Government Quality Assurance is the system by which the government fulfills its responsibility to ascertain that the CQC is functioning and the specified end product is realized. During the construction stage, the Contracting Officer, through his authorized representatives, which include the resident engineer and his staff, is responsible for acceptance testing and quality verification to enforce all specification requirements and for monitoring the Contractor's quality control operations. These functions include, but are not limited to, verification of all operations for compliance with specifications and reviewing and, when required, approving contractor submittals, including certificates of compliance and contractor-developed mixture proportions. If acceptance testing of cement, pozzolan, slag, admixtures, or curing compounds is required, the resident engineer is responsible for making the necessary arrangements for such tests. Government surveillance and acceptance inspection and testing are necessary, starting during aggregate production and continuing through the mixing, placing, and curing of RCC. For the surveillance to be effective, surveillance and inspection personnel must be trained prior to the initiation of construction. This can be achieved by seeking instruction from other Corps personnel who have had experience with RCC and by the use of available training aids in the form of slides and videotapes. In addition, there are periodic seminars and conferences on RCC design and construction sponsored by the Portland Cement Association, American Society of Civil Engineers (ASCE), and ACI. The GQA responsibility is not to be imposed on the construction contractor. If personnel shortages preclude the use of government personnel to accomplish GQA, it should be accomplished by a commercial testing organization under contract to the Government.

(1) GQA representative. This individual may be a government employee or may be an employee of a private engineering firm under contract to the Government and not affiliated with the construction contractor. The GQA representative is the key figure in the operations attendant to concrete quality assurance. The effectiveness of the quality verification operation in ensuring uniformity of the concrete and in obtaining compliance with specification requirements depends to a large degree on the thoroughness with which the quality assurance representative is instructed and trained in the performance of the required duties. Instructions to the GQA representative should be accomplished through training conferences and written guides and instructions prepared by the government materials engineer. Previous experience on similar work is highly desirable. Previous experience cannot entirely compensate, however, for proper instruction and training of quality assurance representatives in the duties unique to a particular project. Preferably, they should be trained for duty on a particular project as the concrete plant is being erected so they may become thoroughly familiar with the plant and particularly those aspects of the equipment bearing on the quality verification procedures. For example, on a large project, the mixing plant quality assurance representative should become familiar with the mixing plant and all of its operating features. All persons assigned as quality assurance representatives should be certified by ACI or have equivalent training. EP 415-1-261, "Quality Assurance Representative's Guide," provides detailed responsibilities and a checklist for the GQA representative.

(2) Engineering and construction guidance. For critical projects such as water-retention dams, it is beneficial for a materials engineer from the district or division office who is knowledgeable of the investigations and design of the RCC project to be detailed to the resident engineer. A qualified materials engineer is necessary to provide critical instructions and oversight for engineering and construction coordination. This individual should be able to provide guidance concerning

adjustment of mixture proportions and to evaluate marginal or substandard material constituents used in the mixture. The materials engineer should not be assigned as part of the inspection team required to ensure that compliance with project specifications is enforced. He should be assigned to provide guidance to the resident engineer and his staff on items which include (a) assessment of lift-surface cleanup compared with that assumed in design, (b) guidance on the reduction of segregation, (c) assessment of mixture proportions for adequacy and consistency, and (d) interpretation of Vebe, nuclear density, and other test results. Generally, he is to provide guidance as to which details of the contract specifications that come into question are the most critical in fulfilling design requirements. The materials engineer should also be responsible for the collection of testing data, evaluation, and writing the final concrete report.

c. CQC program. Contractor Quality Control is the system used by the construction contractors to manage, control, and document their activities and those of their suppliers and their subcontractors to comply with contract requirements. For RCC production there are several areas of concern dealing with the CQC program. One area of concern is maintaining a well-managed and trained CQC staff. This is in part due to the geographical market area from which quality CQC personnel can be drawn. In many areas, qualified personnel with experience and training are not available. Training through ACI and government-sponsored courses will help; however, this is not a substitute for training gained through on-the-job experience. The GQA staff should be aware of this and provide appropriate guidance and training to CQC personnel, especially early in construction.

(1) Three-phase program. The CQC program is specified in the Guide Specifications to consist of a three-part program. Participation in the three-phase control process is necessary to ensure that the contractor is adequately conducting the required control processes. Preparatory and initial-phase meetings are necessary to identify and monitor details of each phase of the construction progress while further identifying certain elements of the contract requirements and determining the acceptability of such. The contractor should prepare minutes of each preparatory and initial meeting involving the CQC/GQA activities in order to properly identify and document the mutual agreements concerning adherence to contract specifications. The final inspection and review should ensure that an acceptable end product quality is achieved.

(2) Personnel requirements. Personnel should have experience or sufficient training in order to perform the various testing and inspections required by the project contract. Adequate communication must be developed between the testing, mixing plant, and placement operations personnel. Generally, the CQC testing requirements alone will dictate the staffing needs for a project. At a minimum, two qualified full-time employees should be available for materials testing in the project lab and at the placement for in-place nuclear density testing. Testing personnel will be required prior to beginning daily mixing operations, throughout production placement, and for follow-up testing after compaction and placement operations have ceased for the day. Testing performed by the contracting officer representative does not relieve the contractor from performing all the testing required by the contract specifications. All work performed by technicians must be in strict accordance with applicable standards to ensure the validity and acceptance of test results.

(3) Project laboratory requirements. A project laboratory facility should be available for use by CQC testing personnel, the contracting officer representative, and any GQA testing personnel. A facility with sufficient floor space to allow for sieving, oven drying, weighing, sample processing, and testing and office space is required. The water and electrical needs for the various test equipment should be met.

d. Quality monitoring and control. Another concern is that CQC organizations often do not respond to or modify, in a timely manner, operations that do not meet specifications. Certain activities such as making aggregate free of moisture or grading adjustments must be addressed immediately to prevent permanent deficiencies. A project GQA program should emphasize monitoring and correcting those features that must be responded to immediately. There are also parts of the specifications that the contractor might not view to be as significant as does the government. As an example, a contractor may try to make the case that an aggregate grading slightly out of specification will not alter the product quality and surely does not warrant stopping RCC production. For such issues, it is best to develop a clear understanding at a high level (government resident engineer and contractor project engineer) of what appropriate actions should be taken to prevent problems from occurring and, when they do occur, how to prevent a similar event in the future. In the example given, it is possible that most of the aggregate has already been produced and there is no practical way to bring the aggregate back into grading. It may be more prudent to analyze the consequences of using the aggregate as is or adjusting the mixture proportions to a new grading curve. Quality control problems associated with specific monitoring or testing can be well defined and are, therefore, usually easier to control.

e. Quality control concerns for RCC. There are many construction procedures used in RCC production that are not defined precisely but, nevertheless, significantly impact RCC production quality. The CQC requirements, intended to ensure that RCC production procedures are accomplished correctly, are not rigidly defined. The following are brief discussions with quality control concerns in these areas:

(1) Lift-surface treatment, protection, and cleanup. Contract specifications usually stipulate when and how a lift surface is to be cleaned prior to the next placement; however, there can be several approaches as to which type of treatment to use and how much treatment will be necessary. The amount of treatment will depend on variables such as weather conditions, whether or not a bedding mortar is used, the condition of the previous lift surface, the interval between placements, etc. Judgment is required by both the government inspector and the contractor in providing the appropriate lift-surface treatment for any particular placement condition. Requiring the contractor to meet “the letter of the law” may, under some circumstances, result in unnecessary delays or cause more problems than solutions.

(2) Actions necessary in preventing segregation. Actions to control or prevent segregation within the RCC can be generally defined; however, due to changing site conditions, procedures may have to be adjusted. An increase in segregation as the RCC comes off the conveyor or out of end-dump trucks will require considerably more dozer action to distribute the segregated materials (rock pockets) and rework them into the surrounding RCC. When RCC becomes dryer, more effort is required by the dozer and vibratory-roller operators to achieve a uniformly compacted material that is free of voids. Segregation is also more likely to occur during RCC start-up operations at the beginning of a shift or when placing RCC and conventional concrete against an abutment (or other hard surface such as pipes, forms, instrumentation blockouts, etc.). The government inspector, placement foreman, dozer operator, vibratory-roller operator, and concrete finishers all must be aware of these and other problem areas and be ready to take necessary action to prevent permanent voids from occurring.

(3) Curing. As with conventional concrete, RCC must be kept continuously moist for the prescribed curing period. However, because of large lift-surface areas and the variable intervals between lift placements, the procedures to achieve the necessary curing will vary throughout the job. Because RCC is dryer than conventional concrete, surfaces tend to dry more rapidly during warm weather. During such conditions, considerable effort will be required to maintain a uniformly moist surface. Contract specifications should address the significance of proper curing of RCC along with minimum equipment and procedures that will be required for curing the RCC. During cool weather or when the interval between lift placement is short, no overt curing action may be called for. Judgment and cooperation between the government inspector and the contractor in developing and agreeing on procedures to be taken ahead of time for various changing conditions will result in the most economical and highest quality product.

(4) Consolidation at interface between RCC and conventional concrete. Consolidation at the interface of RCC and conventional concrete is a critical area of concrete construction that, if not executed properly, can and likely will result in voids. Such voids, because of their location and distribution, may allow leakage through a structure. It is a procedure that is straightforward and will result in a high-quality, void-free product if RCC and conventional concrete are fresh, are of proper consistency, and are consolidated with immersion vibrators on a proper spacing. On a day-in, day-out basis, however, this has been difficult to achieve. This is a construction procedure in which attempts to compensate for a developing problem may actually compound the problem. For example, while extra efforts are being made to consolidate concrete that has begun to set or stiffen in one area, concrete materials in another area are becoming progressively older and thus harder to consolidate. Eventually, a condition develops in which the contractor has lost control and no amount of effort will prevent permanent voids from occurring. The contractor and GQA personnel should be aware of the criticality of necessary rapid adjustments that may be required to prevent this situation. Such adjustments may include immediate addition of extra crews and termination of RCC placement until consolidation of the conventional concrete/RCC interface is again on schedule. Judgment and cooperation should be used in establishing criteria for when and under what conditions these extra procedures are to be initiated.

7-2. Activities Prior to RCC Placement

a. Engineering considerations and instructions for field personnel (ECIFP). Prior to award of a contract for construction which involves concrete features, a report should be prepared by the designer outlining all special engineering considerations and design assumptions and providing instructions to aid the contracting officer’s field personnel in the supervision and quality verification of the construction contract. The information provided will, for the most part, summarize the data contained in the Design Memorandums and include all required formal discussions on why specific aggregate sources, plant locations, structural designs, etc. were selected so that the construction personnel in the field will be provided the necessary insight and background needed to perform reviews of the Contractor's various submittal proposals and to resolve construction conflicts without compromising the intent of the design. This information must not conflict with the project specifications and must not contain any request to change these requirements. In all cases, the contract specification will govern. The designated materials engineer should be intimately familiar with the design and construction of the RCC structure and should develop the ECIFP report with the designer. A typical outline for the concrete construction part of such a report is provided as an aid in EM 1110-2-2000, "Standard Practice for Concrete for Civil Works Structures."

b. Construction coordination. As part of preparation and training prior to the initiation of construction, pre-construction meetings with the field staff in review of contract specification requirements should be held with participation by the designated materials engineer experienced in design and construction of RCC dams. A review of allowable construction techniques, testing, inspections, and investigations required by the contract specifications should familiarize field personnel with potential problems that could be encountered, improper construction techniques, and critical design requirements of the RCC dam. This review should be accomplished prior to scheduling any preconstruction meeting with the contractor. RCC design and construction principles should be understood prior to review and acceptance of contract submittals. The preconstruction meeting between the resident engineer and contract personnel should review materials processing, RCC mixing, transporting, placement, and compaction processes, equipment to be used, required testing, and inspections to be performed in relation to meeting contract specification requirements.

c. Plant calibration. Continuous or batch mixing plants require calibration in order to prove the capability of producing a uniform and homogeneous mixture of RCC. Calibrations are the responsibility of the contractor. Accuracy of batching or proportioning equipment shall be checked and documented for each type of material constituent. The methods for verifying accuracy shall follow recognized standards. Mass or volume checks shall be performed using certified scales, reference masses, or measures. The ability to meet prescribed tolerances of the individual material constituents should be verified and documented for the batch or continuous-mixing operation. All of this should be documented and provided to the Contracting Officer prior to beginning the test section.

d. Test strip. As part of the required continuous or batch mixing calibration process, the contractor should develop a test strip prior to scheduling a test section. The recommended test strip would allow for preliminary evaluation of the RCC mixture proportions produced from the mixing operations and would facilitate calibration adjustments to the plant. Further, it would provide for staging the mixing, transporting, spreading, and compaction equipment in order to evaluate the ability to meet the contract requirements.

e. Test section. As a further aid in training both government personnel and contractor personnel, construction of a project test section by the contractor after award of the contract and prior to start of production operations is essential in almost every case where RCC is an option or requirement. This is discussed in section 5-5. The experience gained on a test section will provide a common basis of knowledge between government and contractor personnel and allows for the contractor to try new and innovative construction techniques in work not affecting the safety or function of the project. The test section also provides an opportunity to adjust the RCC mixture proportions. The test section should be designed to demonstrate the contractor's capability to produce the quality and quantity of RCC required by contract specifications. A project test section should be constructed sufficiently early in the contract to allow the contractor time to increase the size of the batching, mixing, or transporting system, if necessary, to modify placing, spreading, and compaction techniques, or modify any other operation that is considered essential to the success of the job. The test section should not be part of the permanent structure. In many instances, test sections have been constructed in a rapid and uncontrolled manner where it is difficult to assess the results. Appropriate planning, equipment, and personnel should be in place in order to accomplish all tasks and testing necessary. The following is a list of tasks that should be performed and significant features that should be evaluated within a test section:

(1) Evaluate mixture performance

(2) Fabricate a density block for calibration of density gauges

(3) RCC transport and movement activities

(4) RCC placement activities

(5) Avoiding segregation

(6) RCC compaction

(7) RCC curing

(8) Evaluate equipment performance

(9) Evaluate plant production and operation

(10) Personnel training

(11) Installation techniques for panels or other structures

(12) Formwork

(13) Hand work and compaction of RCC

(14) Use of bedding mortar

(15) Lift joint preparation

(16) Evaluate fresh and cold joints

(17) Determine a target density

(18) Performance density testing

(19) Other sampling and testing

7-3. Activities During RCC Placement

a. Placement inspection. The inspector on the placement operations should watch all details related to the overall success of RCC placement operations. The following list indicates some of the items to be checked:

(1) Lift surfaces have been adequately cleaned prior to placement of bedding mortars or RCC. RCC contact surfaces shall be free from ponded water, loose debris, mud or silt accumulations, laitance, coatings or other detrimental material, and loose, unkeyed, or deteriorated rock.

(2) Bedding mortar is placed at the required thickness and correct consistency and is adequately spread.

(3) RCC is deposited, spread, and compacted only on fresh bedding mortar that has not begun to dry or set.

(4) RCC is deposited on lift surfaces in the proper location and spread in the required layer thickness, and the action of the dozers is controlled in a manner to eliminate voids and ensure proper compaction.

(5) RCC as it is deposited and spread is of the required workability as determined by the Vebe tests and by observing spreading and compaction operations.

(6) Compaction of the RCC occurs while RCC is still fresh and has not begun to lose workability.

(7) Lift surfaces are maintained in a moist state at all times.

(8) Internal vibration at interfaces between RCC and conventional concrete is in the right location and done correctly with the right number of immersion vibrators of adequate size and for sufficient duration.

(9) Conventional concrete is deposited and consolidated in those areas where it is required, such as around waterstops and drains, against abutments, and other locations as shown on the plans.

(10) The proper and completed installation of facing panels, embedded items, and facing formwork prior to placement of conventional concrete, mortar, or RCC where applicable.

(11) Installation of contraction joints, if required, is completed prior to compaction by rollers and before RCC has begun to lose workability.

(12) The required passes, determined by concurrent nuclear density testing for the vibratory roller on each lift of RCC, are obtained.

(13) All tests, including Vebe tests, nuclear density tests, aggregate moisture tests, and grading tests, are performed, monitored, and evaluated.

b. Monitoring consistency and workability of RCC. To a very large extent, the stability and watertightness of an RCC structure depend on the mixture proportions used and the resulting consistency and workability of the RCC. The inspector on an RCC placement is responsible for ensuring that RCC consistency and workability are adequate for complete compaction. Two testing procedures should be used at frequent intervals to determine if the RCC being produced is of the correct consistency for compaction. The modified Vebe test is used to determine consistency, and the nuclear density gauge is used to determine if compaction is adequate. The modified Vebe test generally provides a good tool for controlling RCC consistency as an indicator of RCC workability and the ease with which RCC can be compacted. Some projects, however, have encountered difficulty in using the Vebe test to monitor consistency and workability. In these cases, visual observation of the RCC mixing and placement operations becomes the primary tool in monitoring for a quality product. In most instances, the Vebe test can provide the best measure for experienced inspectors by developing their visual observation ability.

c. Monitoring density of RCC. Density measurements are typically performed following RCC compaction efforts using a nuclear density gauge in accordance with CRD-C 64 (ASTM C 1040). A single-probe or double-probe nuclear gauge provides reliable information when large numbers of readings are taken. However, the two-probe gauge provides the capability of monitoring RCC densities at all depths within the limit of fresh RCC and provides a better measure of density at lower depth in a lift.

d. Other tests. Other tests are used for monitoring the consistency of material constituents, for evaluating mixing performance, and for controlling the field placement. Following are descriptions of various test methods used for evaluating RCC:

(1) Grading of fine and coarse aggregates, CRD-C 103 (ASTM C 136). Sieve analyses are performed to monitor aggregate grading as delivered to the mixer. This test procedure allows for tracking consistency while providing control over the potential use of non-uniformly graded materials. Tests are performed at least daily on all aggregates as they are sampled from the stockpiles or mixing plant feed belts. Care should be taken when sampling coarse aggregates from stockpiles by using approved and standardized sampling procedures. Many problems have been encountered from improperly sampled aggregates. Sampling for combined aggregates is generally done at the plant discharge belt. If a discharge belt for combined aggregates is inaccessible or if wide variations occur in those samples, a sample of RCC from the mixing discharge belt can be obtained. The RCC mass of the sample should be determined and it should then be washed over a 75-µm (No. 200) sieve, and a representative moisture content should be determined. The plus 75-µm (No. 200) combined aggregate can then be dried and shaken to determine the grading.

(2) Percent finer than the 75-µm (No. 200) sieve, CRD-C 105 (ASTM C 117). This test is performed in order to monitor the minus 75-µm (No. 200) fines content of coarse and fine aggregates used within the mixture. Variability in minus 75-µm (No. 200) content will lead to mixture proportioning deviations and, at times, affects mixture uniformity, water demand, workability, or strength.

(3) Moisture content determination, CRD-C 113 (ASTM C 566). The moisture content of aggregates and RCC are generally performed using a conventional oven, hot plate, or microwave oven as described in ASTM C 566.

(a) Aggregate moisture. The moisture content of aggregates should be determined at least daily for proper RCC moisture control. Test results allow for initial mixing plant adjustments as well as verification of any changes in moisture condition throughout the day, lending to moisture control at the plant. When admixtures are used, increased testing will be necessary to ensure that aggregates remain wet to avoid losing the effectiveness of the admixture.

(b) RCC moisture content. RCC moisture determination allows for monitoring the mixture as it is discharged from the mixing operation, transported, or placed or immediately prior to compaction.

(4) Vebe testing. The modified Vebe apparatus is described in CRD-C 53. Vebe times are used as an indicator of RCC consistency. Samples of RCC are usually taken from the discharge belt or from the placement prior to compaction. The Vebe time used during construction is determined initially during the mixture proportioning studies. The time is then adjusted as necessary during the preconstruction engineering and design phase of the project when a test strip is constructed. It is later further adjusted when the project test section is built after award of contract. Still further adjustments may be made, as necessary, to the Vebe time during construction. Once a Vebe time is established, the normal procedure is to maintain a consistent Vebe time for the RCC being produced by making batch water adjustments to compensate for changes in aggregate moisture and changes in humidity, wind, and temperature. The batch water adjustments should be made if two consecutive Vebe readings vary from a target Vebe time by 10 sec or more. Changes to the established Vebe time should be made only to improve compactibility and the resulting density. Changes should be made only after consultation with the designated onsite materials engineer who is familiar with proportioning mixtures. Densities can also be determined and monitored in conjunction with the Vebe testing.

(5) Determination of mortar content. Mortar contents of RCC can be determined to verify correct mixture proportions and are normally determined in conjunction with mixer uniformity tests. The test is performed on an RCC sample by washing over a 4.75-mm (No. 4) sieve, determining mass, and comparing with initial moisture and mass of the sample.

(6) Determining target density. To obtain percent compaction, the target density should be developed. It should be determined by one of the following methods;

(a) Upon completion of the mixture proportioning, the optimal wet density is selected. During the test section placement, the target density can be verified or determined from the field prototype test results.

(b) The average maximum density (AMD) is determined from the test section placement and verified periodically with the use of control sections that will be part of the production placement. The control sections should be at least 25 - 30 m (80 - 100 ft) long and 4.5 - 6.0 m (15 - 20 ft) wide. As the control section is compacted, in-place wet density tests shall be made after each pass of the vibratory roller until the maximum density of the lift is achieved. The AMD of the control section should be determined from the average of at least six sites selected by the contracting officer's representative. The AMD should not be accepted until the test section has proven that the mixing, placing, spreading, and compacting operations are satisfactory and that the mixture used produces other acceptable test results.

(c) The soil modified compaction test procedure can be utilized to determine a target density. However, compaction testing is limited by the nominal maximum size aggregate selected for the RCC mixture. Excess quantities of plus 19-mm (3/4-in.) NMSA result in increased aggregate breakage or particle bridging, lending to inconsistent and erroneous densities. The compaction procedure involves the use of a 155-mm- (6-in.-) diam mold, a 4.5-kg (10-lb) sliding sleeve rammer with a 457-mm (18-in.) drop height, and 55 blows per each of 5 layers. The wet density is computed from the measured mass and mold volume of the compacted specimen. For RCC with smaller NMSA mixtures, this method can be another useful tool for monitoring mixture consistency.

(7) Monitoring wet density of RCC. Wet density is monitored in order to control compaction of RCC lifts. Testing for wet density is generally done using a nuclear density gauge with a 305-mm (12-in.) probe. One-minute gauge readings are commonly performed in the direct transmission mode. Data from the nuclear gauge readings can be used during the compaction process to confirm that the mixture proportions are correct for achieving the required densities and for determining if densities are uniform throughout the lift. Field nuclear gauge readings should be compared on a continuous basis with RCC densities measured in the project laboratory.

(a) Gauge calibration. To ensure the accuracy of the nuclear gauges being used, a test block should be made during the early stages of the project and kept available. The nuclear gauges must be calibrated upon initiating the test section and also checked daily against a source of known density. This is accomplished by fabricating a test block or calibration block of RCC to a predetermined density. The calibration block should be at least 457 by 457 mm (18 by 18 in.) by the maximum thickness of one lift plus 25.4 mm (1 in.). The block should be compacted to between 98 and 100 percent of the target density. Once fabricated, the mass of block shall be determined and the block measured to verify actual density, or density may be determined by measuring and determining the mass of cores taken from the block. The block should then be used daily before RCC production begins to calibrate the full-depth readings of the nuclear density gauges. Larger calibration blocks, about 0.76 m^3 (1 yd^3) in size, are commonly produced. This provides a significantly greater mass of RCC while, at times, minimizing nuclear density gauge reading and measurement errors.

(b) Percent compaction. Percent compaction is computed from nuclear density and target density results. Control and acceptance should be determined for compaction requirements based upon design criteria, mixture proportioning design, and test section results.

(8) Temperature, CRD-C 3 (ASTM C 1064). Temperature monitoring should be performed at least daily. When daily ambient air temperatures rise significantly above or below the allowable range of temperature for the RCC, more frequent readings should be documented for both RCC and ambient air.

(9) Air content, CRD-C 41 (ASTM C 231). Air content testing is generally not performed on RCC due to the difficulty in maintaining consistent levels of air content in no-slump concrete. When testing is prescribed, the Type B air meters are most commonly used. RCC is screened over the 37.5-mm (1.5-in.) sieve, placed into the air meter in three equal-volume layers, and consolidated by externally applied vibration such as that provided by a Vebe table or pneumatic hammer. The air meter can also be used to determine the density prior to testing for air content.

(10) Fabricating strength specimens. Strength determination testing of RCC from fabricated specimens is customarily performed during construction. Compressive strength specimens can provide an additional tool for monitoring RCC mixture proportioning performance. Consistency of the RCC mixture significantly affects the ability to produce acceptable RCC specimens that can be correlated to in-place RCC. Specimens are generally consolidated or fabricated by externally applied vibration. Typically, overvibration is not a problem because of the very low entrainment of air within RCC mixtures. Overvibration has been known to produce dense specimens that can misrepresent the strength related to that of the actual in-place density. Alternatively, undervibration of stiff mixtures will produce undesirable voids within the specimens and subsequently result in lower and inconsistent strengths. Two types of molds have been used when producing strength specimens. Most commonly, test specimens are molded in cylindrical split molds made of a hard metal or steel. Conventional single-use plastic cylinder molds, placed within a hard metal cylindrical sleeve or split mold for rigidity under consolidation, have also been successfully used. Methods of consolidation for strength specimens have followed two different approaches:

(a) Making RCC in cylinder molds using a vibrating table, CRD-C-160 (ASTM C 1176). This method produces cylindrical test specimens by applying a surcharge weight and table vibration to each of three equal-volume layers of fresh RCC. Each layer is fully vibrated and consolidated when, by observation, mortar forms a ring around the total perimeter of the surcharge within the annular space between the outer edge of the surcharge and the inside mold wall.

(b) Specimens have also been fabricated using pneumatic pole tampers or electric impact hammers with circular rigid metal tamping plates. Three equal-volume layers of fresh RCC are consolidated in a similar manner as that used with the vibratory table.

e. Recommended frequency of testing. Table 7-1 includes the recommended frequency of testing for a typical RCC dam.

Table 7-1
Frequency of Testing for an RCC Dam

Type of Test	Procedure	Frequency Range volume per test	Comments
Grading of fine and coarse aggregates	CRD-C 103/ASTM C 136	Daily or every 2300 m^3 (3000 yd^3) placed	Monitor as-delivered or blended materials
Percent finer than 75-µm (No. 200) sieve	CRD-C 105/ASTM C 117	Daily or every 2300 m^3 (3000 yd^3) placed	Monitor as-delivered or blended materials
Aggregate moisture content	CRD-C 113/ ASTM C 566	once/shift	Rapid drying methods are also used (hot plate)
RCC moisture content	CRD-C 113/ ASTM C 566	twice/shift	Rapid drying methods are also used (hot plate)
Vebe testing	CRD-C 53	twice/shift	ASTM method utilizes a larger surcharge mass
Mortar content	--	--	Verify proportions
Nuclear gauge calibration	--	daily	Checked against calibration block
Monitoring wet density	CRD-C 64/ ASTM C 1040	10 tests/shift	Tracking performance
Temperature	CRD-C 3/ ASTM C 1064	twice/shift	RCC and ambient air
Air content	CRD-C 41/ ASTM C 231	once/shift	When required
Fabricating strength specimens	CRD-C 160/ ASTM C 1176	once/shift	28-, 90-, and 365-day tests

f. Monitoring test results with control charts. The charting of test results is applied to track material quality, mixing operations, and field placement uniformity. Control charts are used to plot daily test results in relation to specified limits, to determine acceptable ranges, and to identify when problems occur or when trends develop. Upper and lower limits for test results are generally prescribed for production and placement control. Individual test data, averages, moving averages for grouped data, and standard deviations can be further developed from control charts. ACI 207.5R, “Roller Compacted Mass Concrete,” provides a good example of control charting for individual test data, standard deviation, average, and moving average for 50 tests. The following tests allow for monitoring consistency of test results through the use of control charts:

(1) Fine and coarse aggregate moisture contents. Absorption can be determined as the lower limit. Moisture contents greater than 1-2 percent above absorption are desired, especially when admixtures are included in the RCC mixture.

(2) RCC moisture content. Several tests daily are recommended. The optimal moisture content is determined from the mixture proportioning study and verified or adjusted during the test section placement. Moisture content is generally expressed as the percent mass of water over the total mass of material. The moisture content should be controlled to within ± 0.2 percent of the optimum.

(3) Grading - minus 4.75 mm (No. 4), minus 75 µm (No. 200). Percentage passing the 4.77-mm (No. 4) and 75-µm (No. 200) sieves can be monitored through control charts for the coarse and fine aggregates. Limits are provided with contract specifications or from recommended size grading requirements such as those provided in Tables 3-1 and 3-2.

(4) Fineness modulus for fine aggregate. The fineness modulus is useful for tracking consistency of the fine aggregate as delivered and used within the RCC mixture. Limits of 2.10 and 2.75 are typically applied, as shown in Table 3-2.

(5) Vebe times for RCC. Vebe testing monitors the consistency of the mixture and allows for performance tracking of the mixing operations. Vebe times of 15 to 20 sec are desirable.

(6) Wet density of the RCC. Nuclear density gauge results are monitored throughout production placement. Some comparisons between control charts for RCC moisture content and wet density reveal where problems occur in the RCC placement. Trend lines falling below the minimum allowable compaction limit may require a review of the mixing operations or a mixture adjustment. The designated materials engineer should review all test results in order to eliminate any other possibilities prior to making mixture adjustments.

(7) Temperature monitoring of the RCC and ambient air. Charting temperature will document the highs and lows and can aid in identifying potential problems on or during particular days within production placement. RCC with temperatures exceeding the specified upper limits may require action to cool the mixture. Tracking ambient temperature will help enforce decisions concerning mixing and placing modifications.

g. Visual observation as an inspection tool. An inspector should be present at all times that RCC is being placed to observe the details listed. To determine if RCC, as delivered, spread, and compacted, is of the correct workability, some visual features should be observed. Visual inspection of the RCC mixture should verify adequate surface coating of the aggregate with paste or mortar. Usually, if the RCC is too dry for proper compaction, obvious signs are: (1) increased segregation of the mixture, (2) aggregate particles on the surface which are cracked by the roller, and (3) little or no reworking of the RCC adjacent to the dozer as the RCC is spread. Cracking of aggregate particles creates a visible scattering of rock flour around the aggregate particles. In addition, concrete which is too dry will not show the development of paste at the surface after three or four roller passes as it should, and individual larger-sized aggregate particles will begin to dry within 10 - 15 min after spreading during warm weather. If closely spaced surface cracking is observed as the roller moves over the surface, the mixture is probably slightly dry. The RCC is likely too wet if heavy equipment produces deep rutting or if surface bleeding of water is observed. The mixture proportions, therefore, may have to be adjusted. An increase in segregation of large aggregate particles from the mixture may be caused by too much or too little water. This condition should be reported by the inspector and corrected as soon as it is observed.

7-4. Postconstruction Activity

a. Drilling program. Samples of RCC can be obtained from coring in order to determine the in situ properties. This provides the best evidence of concrete performance by providing samples for strength and density determination, for viewing the density matrix from top to bottom of the lifts, and for identifying lift joint bond or lack of bond. The primary purpose for obtaining intact lift joints is to determine the performance of shear and tensile strength properties in relation to those used for design. Generally, coring is performed upon completion of the RCC structure. It can also be performed during planned cold joints such as during the planned gallery construction. Skid-mounted or truck-mounted hydraulic coring rigs have successfully obtained intact RCC and foundation cores. Conventional core barrels with a split inner barrel, about 1.5 m (5 ft) in length and 155 mm (6 in.) in diameter, are commonly used for RCC core sampling. Some core breakage occurs where weak lift joints shear during coring. Experienced and careful drillers typically have greater core recovery with intact lift joints. The use of a polymer drilling fluid has also improved recovery of lift joints.

b. Instrumentation. Structural behavior instrumentation programs used in RCC dams are similar to those used in conventional concrete dams. Instrumentation is generally used to monitor temperature, stress, strain, and/or hydrostatic pressure. The extent of instrumentation should result from an evaluation determining the number, type, and location within the structure. The instrumentation program should be designed to avoid interference with rapid placement of RCC and to minimize construction associated with installation. Details and guidance on the planning of instrumentation programs, types of instruments, and the preparation, installation, and collection of data are provided in EM 1110-2-4300, "Instrumentation for Concrete Structures."

c. Documentation. A concrete report will be completed at the conclusion of construction on any major concrete structure such as a concrete dam. The specific requirements for a concrete report are outlined in ER 1110-1-1901, "Project Geotechnical and Concrete Materials Completion Report for Major USACE Projects." The concrete report will serve the dual purpose of meeting the requirements of ER 1110-2-100, "Periodic Inspection and Continuing Evaluation of Completed Civil Works Structures," for engineering data retained at the project site and of advancing the state of the art of constructing large concrete structures by providing personnel working on subsequent projects with a discussion of problems encountered and solutions devised. Construction performance summaries, within the concrete report, should include any developed control charts from test data and should include a discussion of any data trends. Inspection review should include a summary of problems encountered with material storage, mixing, transporting, placing, spreading, compacting, and curing. Any solutions to problems or decisions made concerning modification to the design specifications of the RCC should also be provided in a summary. The postconstruction report should also include an evaluation of the results of strength tests on cores extracted from the structure.

(1) Author. Personnel who are familiar with the project should complete the concrete report, preferably the materials engineer assigned to the project. Personnel from the engineering division should contribute to the report in any areas where they have special knowledge.

(2) Timing. The report should be written as the project progresses so that important information is not lost as personnel changes occur. The report should be completed within 120 days of substantial completion of concrete placing.