Guide for Developing RCC Specifications and Commentary

Roller-Compacted Concrete for Embankment Armoring and Spillway Projects

Prepared by Gannett Fleming, Inc.

Concrete Thinking for a sustainable world
PCA Portland Cement Association

Guide for Developing RCC Specifications and Commentary

RCC Specifications for Embankment Armoring and Spillway Projects

By Rodney E. Holderbaum and Paul G. Schweiger of
Gannett Fleming Inc.

PCA
Portland Cement Association
5420 Old Orchard Road
Skokie, Illinois 60077-1083
847.966.6200 Fax 847.966.9781

500 New Jersey Avenue NW, 7th Floor
Washington, DC 20001-2066
202.408.9494 Fax 202.408.0877
www.cement.org

An organization of cement companies to improve and
extend the uses of portland cement and concrete
through market development, engineering, research,
education, and public affairs work.

Acknowledgements:

This *Guide for Developing RCC Specifications* was prepared for the Portland Cement Association under the supervision of Mr. Randall P. Bass and Mr. Wayne Adaska. The primary authors of the Guide were Rodney E. Holderbaum and Paul G. Schweiger of Gannett Fleming Inc., with technical input from Ernest K. Schrader. The primary authors of the *Commentary* were Rodney E. Holderbaum, Paul G. Schweiger, and Randall P. Bass. Technical review and editing were provided by:

William B. Bingham, Gannett Fleming Inc., Technical Review
Donald P. Roarabaugh, Gannett Fleming Inc., Technical Review and Editing
Stephen Tatro, Corps of Engineers, Technical Review - Materials
Jeffrey Allen, ASI-RCC Inc., Technical Review - Construction Issues
Fares Y. Abdo, Portland Cement Association, Second Printing Technical Review and Editing

Cover photo credits:

Top: Siegrist Dam, Schuylkill County, PA

Middle: Yellow Creek Dam No. 14, Gwinnett County, Georgia

Bottom: Elkwater Fork Dam, Randolph County, West Virginia

Printing history:

First printing: 2000

Second printing: 2007

ISBN No. 0893122521

EB214.02

WARNING: Contact with wet (unhardened) concrete, mortar, cement, or cement mixtures can cause SKIN IRRITATION, SEVERE CHEMICAL BURNS (THIRD DEGREE), or SERIOUS EYE DAMAGE. Frequent exposure may be associated with irritant and/or allergic contact dermatitis. Wear waterproof gloves, a long-sleeved shirt, full-length trousers, and proper eye protection when working with these materials. If you have to stand in wet concrete, use waterproof boots that are high enough to keep concrete from flowing into them. Wash wet concrete, mortar, cement, or cement mixtures from your skin immediately. Flush eyes with clean water immediately after contact. Indirect contact through clothing can be as serious as direct contact, so promptly rinse out wet concrete, mortar, cement, or cement mixtures from clothing. Seek immediate medical attention if you have persistent or severe discomfort.

Guide for Developing RCC Specifications

TABLE OF CONTENTS

INSTRUCTIONS FOR USE OF THIS GUIDE DOCUMENT

Information to assist the engineer with preparation of a specification for embankment armoring or spillway construction using roller-compacted concrete is provided in two different formats within this document: (1) the *Guide for Developing RCC Specifications,* and (2) the *Commentary*. The *Commentary* is a companion document that provides additional guidance for specifying equipment, materials, and construction procedures. The *Guide for Developing RCC Specifications* was prepared using the CSI specification format.

The following paragraph titled "A. Schedule:" illustrates the use of the Guide Document. The items bracketed in bold type, (e.g. **[6 days], [one 10-hour], [April 15]**) are items or information that are project specific and need to be provided by the specification writer. The italicized paragraph following the specification is not part of the specification and is denoted as a separate comment by the asterisks. This portion of the Guide Document is used to provide information to assist the specification writer with preparation of that particular specification section.

Example:

3.01 SCHEDULE AND WEATHER RESTRICTIONS

A. Schedule: It is the intent of this specification to construct the RCC in a continuous operation to the extent practical. Weather permitting, schedule RCC placement **[6 days]** per week **[one 10-hour]** shift per day from the start of placement until completion. Begin placement no later than **[April 15]** and complete by **[June 15]** of the **[same year]**.

Insert placement time limits if required to limit peak temperatures and/or if the owner or local municipality has schedule or regulatory requirements that affect the contractor's production schedule.

Insert the appropriate dates paying attention to local climate conditions. For armoring and overtopping projects, temperature sensitivity is generally not a major concern. The RCC placement window should be wide enough to afford the contractor flexibility.

PART 1 - GENERAL

1.01 DESCRIPTION:

A. Scope: This section describes requirements for furnishing all plants, materials, and equipment, and performing all labor for the manufacturing, transporting, placing, compacting, testing, and curing of roller-compacted concrete (RCC).

B. Definition: Roller-compacted concrete is a combination of crushed rock and/or natural sand, gravel, and/or soil having a controlled gradation to which cementing materials such as cement or cement and pozzolan are added. The materials are blended with water to a damp consistency that can be hauled in vehicles or delivered with a conveyor, spread with earth-moving equipment in layers, and compacted with a vibratory roller.

1.02 REFERENCES, SPECIFICATIONS, CODES, AND STANDARDS:

A. Applicable Publications:
1. "Roller-Compacted Concrete," Symposium Volume of the American Society of Civil Engineers, May 1985.
2. "Roller-Compacted Concrete II," Symposium Volume of the American Society of Civil Engineers, February 1988.
3. "Roller-Compacted Concrete III," Symposium Volume of the American Society of Civil Engineers, February 1992.

B. American Concrete Institute:
1. ACI 207.5, *Roller-Compacted Mass Concrete*
2. ACI 211.1, *Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete*
3. ACI 214, *Recommended Practice for Evaluation of Test Results of Concrete*
4. ACI 304, *Guide for Measuring, Mixing, Transporting, and Placing Concrete*
5. ACI 305, *Hot Weather Concreting*
6. ACI 306, *Cold Weather Concreting*
7. ACI 308, *Standard Practice for Curing Concrete*
8. ACI 309, *Guide for Consolidation of Concrete*
9. ACI 318, *Building Code Requirements for Structural Concrete*

C. American Society for Testing and Materials:

1. ASTM C 31, *Practice for Making and Curing Concrete Test Specimens in the Field*
2. ASTM C 33, *Specification for Concrete Aggregates*
3. ASTM C 39, *Test Method for Compressive Strength of Cylindrical Concrete Specimens*
4. ASTM C 40, *Test Method for Organic Impurities in Fine Aggregates for Concrete*
5. ASTM C 42, *Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete*
6. ASTM C 87, *Test Method for Effect of Organic Impurities in Fine Aggregate on Strength of Mortar*
7. ASTM C 94, *Specification for Ready-Mixed Concrete*
8. ASTM C 127 *Test Method for Specific Gravity Absorption of Coarse Aggregate*
9. ASTM C 128 *Test Method for Specific Gravity Absorption of Fine Aggregate*
10. ASTM C 131, *Test Method for Resistance to Degradation of Small Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine*
11. ASTM C 138, *Test Method for Unit Weight, Yield, and Air Content (Gravimetric) of Concrete*
12. ASTM C 143, *Test Method for Slump of Hydraulic Cement Concrete*
13. ASTM C 150, *Standard Specification for Portland Cement*
14. ASTM C 156, *Test Method for Water Retention by Concrete Curing Materials*
15. ASTM C 172, *Practice for Sampling Freshly Mixed Concrete*
16. ASTM C 173, *Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method*
17. ASTM C 192, *Practice for Making and Curing Concrete Test Specimens in the Laboratory*
18. ASTM C 231, *Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method*
19. ASTM C 260, *Specification for Air-Entraining Admixtures for Concrete*
20. ASTM C 295, *Guide for Petrographic Examination of Aggregates for Concrete*
21. ASTM C 470, *Specification for Molds for Forming Concrete Test Cylinders Vertically*
22. ASTM C 494, *Specification for Chemical Admixtures for Concrete*
23. ASTM C 535, *Test Method for Resistance to Degradation of Large Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine*
24. ASTM C 566, *Test Method for Evaporable Moisture Content of Aggregate by Drying*
25. ASTM C 595, *Standard Specification for Blended Hydraulic Cements*
26. ASTM C 618, *Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete*
27. ASTM C 685 *Specification for Concrete Made by Volumetric Batching and Continuous Mixing*
28. ASTM C 1040 *Test Methods for Density of Unhardened and Hardened Concrete in Place by Nuclear Methods*
29. ASTM C 1170 *Test Methods for Determining Consistency and Density of Roller-Compacted Concrete Using a Vibrating Table.*
30. ASTM C 1435, *Molding Roller-Compacted Concrete in Cylinder Molds Using a Vibrating Hammer*
31. ASTM D 3042, *Test Method for Insoluble Residue in Carbonate Aggregates*
32. ASTM D 4318, *Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils*

D. American Association of State Highway and Transportation Officials, AASHTO M182 burlap cloth made from jute or kenaf.

1.03 DELIVERY, STORAGE, AND HANDLING

A. Cement and Pozzolan:

1. Transportation of Bulk Cement and Pozzolan: Transport cement and/or pozzolan from the railhead, mill, or intermediate storage to the mixing plant in adequately designed weather-tight trucks, conveyors, or other means that completely and thoroughly protect the cement or pozzolan from exposure to moisture.
2. Temperature of Cement: Deliver cement to the jobsite at a temperature not exceeding 160 °F. The temperature of the air used to transport cement into storage containers or silos must be less than 180 °F. The temperature of the air will be determined by measuring the temperature on the outside of the transport pipe with a surface thermometer.
3. Storage: Immediately upon receipt at the concrete plant, store cement and pozzolan in a dry, weather-tight and properly ventilated structure. All storage facilities are subject to approval and must permit easy access for inspection and identification. Store sufficient cement and pozzolan to complete at least **[5 hours]** of placement at the typical production rate being experienced. To prevent cement and pozzolan from becoming unduly aged after delivery, use any cement or pozzolan that has been stored at the site for **[60 days**} or more before using cement and pozzolan of lesser age.

B. Aggregates: Aggregate requirements are covered in Paragraphs 2.01 and 3.04. The contractor's responsibility includes providing and delivering aggregates to the site, monitoring delivered quantities, and stockpiling in a manner preventing segregation, intermixing, and contamination.

C. Admixtures: Deliver admixtures to site in original manufacturer's containers. Store and handle in accordance with manufacturer's printed instructions.

1.04 SUBMITTALS

A. General Requirements: Submit all required information within **[30 calendar days]** following **[Notice-to-Proceed] [or before start of RCC construction]** with the contract unless otherwise specified.

Insert time requirements for submittals as appropriate.

B. RCC Mixing Plant(s) and Equipment:

1. RCC Mixing Plant:
   a. Submit a schematic drawing and narrative description of the RCC mixing plant and its anticipated peak and sustainable production rates.
   b. Submit detailed procedures for calibrating plant and monitoring materials used during construction.
   c. Submit calibration report prior to initiating trial placement.
2. RCC Handling and Conveying: Submit description of anticipated equipment for transporting, placing, compacting, and handling roller-compacted concrete.
3. If equipment needs vary during the course of RCC production and placement, submit the above items for each planned phase of work.
4. Cementitious Materials Storage: Submit a report on total capacity of all on-site storage facilities including silos, pigs, etc.
5. Submit a plan for curing completed exposed RCC surfaces.

C. Materials:

1. Cement and Pozzolan: Submit source(s) of cement and pozzolan. Submit samples as specified in Paragraph 2.02 D.
2. Aggregates: Submit source(s) of all aggregates. Submit samples as specified in Paragraph 2.02 D. Submit delivery schedule as specified in Paragraph 3.04 D.
3. Delivery Schedule: Submit delivery and production (where applicable) schedule for all materials.

D. Bedding Mix Design: Submit mix design and test results for bedding mix showing that the selected mix meets the requirement of Paragraph 2.01 F. Submit 28-day compressive strength test results no later than **[60 days]** following Notice-to-Proceed.

E. Delivery Plan: Submit a plan for transporting the RCC aggregates from the aggregate plant(s) to the RCC plant site. Include a map showing the proposed haul route(s); traffic control measures; the number, type, and weights (fully loaded) of haul vehicles to be employed, clear height at overpasses, and weight restrictions for all bridges located along the proposed route(s).

F. Delivery Tickets: Submit delivery tickets for each delivery of cement, pozzolan, and bedding mix. Include the source, date manufactured or produced, type or class, contractor's name, project name, and a certification that the material meets the specification requirements. Include the following information on each delivery ticket for each load or batch of bedding mix:

1. Name and location of batch plant
2. Ticket number
3. Load and truck number
4. Date
5. Destination
6. Concrete class
7. Batch weights for all materials
8. Amount of concrete
9. Time mixer charged with concrete
10. Recording of revolution counter (transit-mixed concrete)
11. Space for initials of receiving party

G. Personnel: Provide an organization chart showing key individuals to be assigned to production and placement of roller-compacted concrete. For each individual on the organization chart, provide a resume showing applicable experience on similar projects, total years of experience, duration of each assignment, names of similar projects, client names, addresses, and phone numbers, and nature or responsibility on each assignment. At a minimum, include the Project Manager, Project Superintendent, RCC Production Supervisor(s), RCC Placing Supervisor(s), and Quality Control Manager or Engineer on the organization chart.

The need for this paragraph and the details of requested information vary with each project. If contractors are prequalified prior to bidding, this paragraph can be omitted from the specification. For some projects it may be appropriate to require this information to be submitted with the bids. If the qualifications are used to select the "lowest qualified bidder," qualification requirements must be included in the bid documents.

H. Quality Control Plan: Submit Quality Control Plan addressing all items discussed in Paragraph 3.16.

I. Hot and Cold Weather Concreting: Submit proposed plan for placing RCC during hot and cold weather conditions. Include planned procedures for heating and/or cooling materials, use of admixtures, and protection of completed work.

1.05 TESTING BY ENGINEER DURING CONSTRUCTION

A. General: The engineer will perform testing prior to and during construction to determine RCC mix proportions and compliance with the specifications. Cooperate with the engineer and provide access to all parts of the site and provide access and facilities for collection of all material samples as necessary during all phases of the project.

B. Anticipated Testing Program: Testing by the engineer is anticipated to include, but is not necessarily limited to, the following items:

1. RCC Mix Testing: Mix testing of RCC to determine the appropriate mix proportions for the project. This testing will be performed using representative material samples provided by the contractor as described in Paragraph 2.02 D.
2. Trial Placement Testing: Verification testing and inspection to determine that the RCC mix is produced and placed as intended by the specifications.
3. Production Placement Testing: Testing and inspection to determine that the RCC mix is produced and placed as intended by the specifications.
4. Post-Production Testing: Testing of samples prepared during construction to determine that the in-place material meets the requirements of the specifications.

C. Contractor Responsibility: Testing performed by the engineer does not relieve the contractor of his responsibility for performing all of the tests and inspections required by Paragraph 3.16, QUALITY CONTROL AND TESTING.

PART 2 - PRODUCTS

2.01 MATERIALS

A. General: Roller-compacted concrete will be composed of portland cement, pozzolan (if required), aggregates, retarding admixture (if required), and water.

B. Substitutions and Alternate Sources: Substitutions or alternate material sources will not be permitted without advance approval by the engineer.

C. Cementing Materials:

1. General: Provide portland cement that conforms to the requirements of ASTM C 150 or ASTM C595 **[Type I], [Type II], [Type V]**. If used, provide pozzolan that conforms to ASTM C 618, **[Class C], [Class F].** Furnish cement and pozzolan in bulk quantities to the jobsite. **[See Commentary for additional discussion.]**

2. Acceptance Requirements and Tests: Consistently supply cement and pozzolan with similar chemical and physical properties. Routinely check the chemical and physical properties of the cementitious materials for conformance with the specifications. Provide copies of all test results representing material sent to the jobsite prior to unloading those materials at the jobsite. Cement (and pozzolan, if used) may be subjected to spot testing by the contractor or engineer for samples obtained at the mill, at transfer points, and at the project.

D. Aggregates:

1. General: **[Produce] [Purchase, deliver],** and stockpile aggregate for production of RCC as described in Paragraph 3.04.

2. Quantity: Provide necessary aggregate to allow for overbuild, stockpile bases, trial placement, testing, waste, and materials used for contractor's convenience.

3. Production and Delivery Schedule: Unless otherwise approved, maintain sufficient quantities of aggregate on-site for a minimum of **[two weeks]** of RCC placement at the maximum anticipated production rate.

4. Gradations: Meet the gradation requirements shown in Table 2-1.

5. Plasticity Index: The PI of the aggregate should be less than **[5]**

Insert gradations for all-in-one aggregate blend or for each size group as appropriate. See Commentary for additional discussion related to selection of aggregates.

Table 2-1: Gradations of RCC Aggregates

Sieve size	Percent finer by weight		
	Fine aggregate	**Coarse aggregate**	**All-in-one aggregate**
2 inch	100	100	100
1-1/2 inch	100	100	100
1 inch	100	95-100	97–100
3/4 inch	100	-	-
1/2 inch	100	25–60	63–80
3/8 inch	100	-	-
#4	85–100	0–10	40–55
#8	-	0–5	-
#16	45–65	-	-
#30	35–50	-	-
#40	-	-	15–25
#100	10–25	-	-
#200	5–10	0–2	4–10

E. Water: Provide water that meets the standard requirements for ready-mixed concrete as established in ASTM C 94, *Standard Specification for Ready-Mixed Concrete.* **[See Commentary for additional discussion.]**

F. Bedding Mix: Use bedding mix as shown in the drawings between the foundation or abutment and RCC and wherever required between layers of RCC. Retard bedding mix so that its initial set time exceeds 3 hours at 95 °F. It may be retempered within this time period before it is spread on the foundation or lift surface. However, the water-cementitious ratio of the mix after retempering shall not exceed the water-cementitious ratio of the approved bedding mix. Spread bedding so that the maximum thickness over rock foundations does not exceed 2 inches. Spread bedding mix to a minimum thickness of **[1 inch]** on rock foundations and **[3/8 inch]** on RCC lift surfaces. Spread RCC over the bedding and begin compacting into it within 45 minutes of when the bedding mix was discharged. Use mix proportions developed by the contractor, based on trial mix testing approved by the engineer. Use materials of the same type and from the same source as those used for the trial-mix testing. Proportion the bedding mix within the following general guidelines:

Slump (placed on RCC) . . . . 5 to 9 inches

Maximum aggregate size . . . . **[3/8 inch]**

Percent passing #200 sieve (aggregate) . . . . **[2% maximum]**

Water reducing admixture . . . . may be required

Design strength (28 day) . . . . **[2500 psi]**

Retarder . . . . as required to achieve the required delayed set time

Admixtures may be introduced into the mix to maintain its workability. Proportion the mix to be very workable and to minimize segregation. Batch bedding mix either on-site or offsite and transport to the lift surface by crane and bucket, transit truck mixer, pump, or other methods approved by the engineer. Do not use conveyor delivery unless it can be demonstrated that the mix can be transported on the conveyor without any segregation. Pozzolan may be substituted for cement, up to a maximum of 30% by volume, provided that all specification requirements are met.

Minimum thickness is the same as the MSA but not less than 3/8 inch. The design strength of the bedding mix must equal or exceed the design strength of the RCC.

G. Chemical Admixtures: Provide water reducing agent and retarding admixture that conforms to ASTM C 494, type D, and water reducing admixture that conforms to type A requirements. Provide dose rates in accordance with the approved mix design and mix as recommended by the manufacturer. **[See Commentary for additional discussion.]**

Insert requirements for any other materials special to your project.

H. Joint Materials: Provide and install joint materials in accordance with **[Section 03250.]**

Not required if joints are not included in design.

2.02 MIX DESIGN(S)

A. General: Roller-compacted concrete mix proportions will be determined by the engineer.

B. Mix Proportions: The anticipated RCC mix design(s) are approximated in Table 2-2 based on preliminary evaluation of potential aggregate, cement, and pozzolan sources (weights are based on saturated surface-dry aggregate). The final mix design(s) will be determined from testing performed by the engineer using representative materials provided by the contractor.

Table 2-2: Approximate RCC Mix Proportions

	Weight in pounds per cubic yard					
				Aggregate		
Mix	**Cement**	**Pozzolan**	**Free water**	**Fine**	**Coarse**	**All-in-one**
A						
B						

Insert estimated mix proportions as appropriate. Specify all-in-one aggregate proportions or individual fine and coarse aggregate proportions.

C. Mix Adjustments: Adjust mix water content based on continuous routine monitoring to obtain optimum compaction during all weather conditions. Do not adjust cement, pozzolan, or aggregate contents without written approval or direction from the engineer. Cement and pozzolan adjustments will only be permitted or directed after development of sufficient supporting test results indicating justification for the adjustment.

D. Material Samples: Submit representative production samples of cement, pozzolan, and admixtures to the engineer's laboratory **[provide address, phone number, and contact]** within **[30 calendar days]** following Notice-to-Proceed. Submit samples that are representative of those proposed for the project and include manufacturer's test reports indicating compliance with applicable specification requirements and showing all chemical and physical properties. Identify all materials with labels and/or tags as appropriate. Provide minimum quantities of materials as shown in Table 2-3.

Table 2-3: Minimum Quantities of Materials for Testing

Material	Quantity
Fine aggregate	**[2 tons]**
Coarse aggregate	**[2 tons]**
Cement (in barrels or sealed sacks)	**[0.3 ton]**
Pozzolan (in barrels or sealed sacks)	**[0.2 ton]**
Water	**[As requested by engineer]**
Admixtures	**[1 gallon each]**

If an all-in-one aggregate is selected, 4 tons should be submitted. The submittal time and quantities of materials will vary depending on the individual schedule and other requirements. The engineer should insert submittal time and quantities as appropriate.

2.03 EQUIPMENT

A. General: Provide sufficient equipment as described by these specifications and the contract drawings.

B. Equipment Substitutions: After equipment is demonstrated as suitable for production and placement, as indicated by contractor submittals, calibration report(s), mixer uniformity test results, and the trial placement, no substitution of equipment will be permitted without prior written approval by the engineer.

C. RCC Mixing Plant(s):

1. General: Select the RCC mixing "plant" to be used and determine its layout. The plant includes all necessary mixers, volumetric or weight controls, storage bins, feed systems, and discharge mechanisms. Provide the RCC mixing plant at the site, in-place, in operating condition, and calibrated prior to the start of the trial placement. Do not initiate trial placement until written calibration and uniformity test reports have been submitted to, and approved by, the engineer. Provide plant(s) capable of routinely and consistently producing well-mixed RCC and with demonstrated satisfactory performance with similar mixes. The minimum sustainable capacity of the plant(s) must be at least **[200 tons]** per hour using the specified mixes

See Commentary on mixing plant capacity requirements.

2. Description: Provide twin shaft paddle-type continuous mix or batch-type "pugmill" plant(s). Do not charge mixers in excess of the capacity recommended by the manufacturer for RCC. Provide mixers capable of combining the materials into a uniform mixture and capable of discharging this mixture without segregation. Batch-type drum mixers may also be submitted for approval provided that they have proven satisfactory with similar mixes and can meet the required production rates. It must also be demonstrated that they have low maintenance, available spare parts, and the ability to meet variability requirements. Traditional drum-type mixers must demonstrate that the specific plant consistently meets uniformity requirements specified herein. The plant's transfer systems must be capable of charging and discharging the constituents and the mixed product without bridging or choking.

3. Mixing Time:

   a. Batch-Type Drum Mixers: The minimum mix retention time should be **[90 seconds]**. Prior to the test section, mixer uniformity tests, performed in accordance with Section 2.03C must be performed. Longer mixing times will be required if needed to meet the tolerances in Table 2-4.

   b. Continuous Mixing or Compulsory-Type Pugmills: The minimum mixing time for continuous mixing pugmills or batch-type (compulsory) pugmills is **[15 seconds]**. If the plant proposed by the contractor has successfully mixed RCC of similar proportions and the plant operator has experience both with RCC mixing and the proposed plant, no mixer uniformity tests are required unless the engineer determines there are problems with the consistency of the RCC mix. At the direction of the engineer, perform mixer uniformity tests. If the plant fails to meet the tolerances shown in Table 2-4, increase the mixing time to achieve compliance with Table 2-4 or use a new plant. Regardless of the type of mixing plant used, if it fails a uniformity test, no production work can begin or resume until a satisfactory test is performed.

4. Uniformity Tests: Where the proposed mixing plant does not have a record of successfully mixing RCC similar to that required for the project, perform a set of three mixer uniformity tests. The tests required for each set of uniformity tests is are shown in Table 2-4. Take all samples for testing from the placement area following spreading of the material. A mixing plan will be considered acceptable provided that tolerances for 6 out of the 7 tests listed in Table 2-4 are met.

   a. Batch-Type Mixers: For batch-type mixers, perform each set of uniformity tests on separate batches of roller-compacted concrete taken near the beginning, middle, and end of a shift of placement.

   b. Continuous Mixers: For continuous mixers, perform each set of uniformity tests on samples taken near the beginning, middle, and end of a shift of placement.

The following notes may be included in the specification if desired.

NOTES ON UNIFORMITY TESTS:

a. Base calculation of "Maximum Difference" values on results of samples taken from the placement area after spreading and immediately before compaction. This will include the beneficial or detrimental effect of additional handling and re-mixing from hauling, transferring, and spreading.

b. Charging procedures into the mixer can have a significant effect on mixer performance.

c. The RCC mix in loose form contains no paste slurry, but does have considerable "bulking." Mixers may not be able to be loaded to their full rated capacity without spilling or due to poor mixer performance.

Table 2-4: Allowable Tolerances of RCC Uniformity Tests

Test	Allowable maximum difference (See note 1)	ASTM Standard
Water content of full mix (percent by weight)	15%	D 2216
Coarse aggregate content of concrete (plus No. 4, percent by weight)	15%	C 94 (Annex)
Unit weight of air-free mortar (lb/y^3)	2%	C 94
Air content of full mix	100%	C 231
Wet unit weight (density) of full mix	2%	C 1170
Compressive strength at 7 days	25%	C 39
Vebe time	15%	C 1170

(1) Maximum allowable difference = (maximum value minus minimum value, divided by average of three tests).

5. Aggregate Bins: For each size group of aggregate, provide separate feed bins or compartments with steep side slopes, large gate openings, and capable of handling aggregate in a damp condition without choking. Provide bins with sufficient capacity to continuously supply the mixer operating at full capacity. Unless the aggregates in the bins are readily visible to operating personnel, equip each aggregate bin with mechanical or electrical sensors to indicate when aggregate in any bin is below the level to permit accurate delivery to the mixer.

6. Cement and Pozzolan Silos: Provide individual silos for bulk portland cement and pozzolan (if used) with ample size and so constructed that the various materials will remain separate under all working conditions. Separate all compartments containing cement (and pozzolan) from each other by a free draining air space. Clearly mark cement and pozzolan silos with signs to indicate the material contained in each silo.

7. Water Dispenser: Provide a water dispenser that is capable of dispensing the mix water within the specified requirements. Provide piping, valves, and other components that are free from leakage for delivering water to the mixer(s). Water may be weighed or metered by an in-line volumetrically activated flow meter. The valve must be capable of gradual adjustment during the mixing process to compensate for varying moisture contents in the aggregates. Use valves that are automatically controlled and close if cement, pozzolan, or aggregate stops entering the mixer at the required rate. This control may be bypassed for cleaning operation.

8. Sampling Facilities: Provide suitable facilities and labor for obtaining representative samples of materials as they enter the mixer, are discharged from the mixer, are discharged from gob hoppers, and from the placement after spreading but before compacting. Furnish all necessary platforms and equipment for obtaining samples.

D. Conveyors: Design and/or provide conveyors and transfer components for low maintenance, continuous operation with clean return belt surfaces and without segregation or excessive loss of material. **[Fit all belts with covers or shields to prevent drying by the wind and sun, and over-wetting from rain.]**

For conveyors that result in limited exposure time on the belts or during placement in cool weather, the requirement for covers can be omitted.

E. Haul Vehicles: RCC may be hauled using trucks, large front-end loaders, or scrapers from the **[plant discharge] [conveyor discharge]** to various locations on the placement area. Tracked haul vehicles will not be permitted. Use bottom-dump haul vehicles, end-dump trucks with special tailgates or drop control methods that demonstrate an ability to handle dumping without excessive segregation, and/or front-end loaders. The haul vehicles must be free of deleterious materials including, but not limited to, oil, grease, loose, deteriorated, or dry RCC, and soil. The maximum free fall drop height from hauling vehicles is 5 feet.

F. Temporary Storage Containers: For continuous mixing plants provide a gob hopper or holding device for RCC temporarily accumulated after mixing and while waiting to be loaded into a hauling vehicle for transport. The gob hopper is not required if a total conveyor system without haul vehicles is used.

G. Chutes and Drop Tubes: Unless specifically authorized in writing, chutes or uncontrolled drops exceeding 5 feet will not be permitted.

H. Spreading Equipment: Provide equipment for spreading compatible with the capacity of the plant, delivery systems, and size of the work area. Equipment must be capable of placing the RCC in uniform lifts and without segregation.

Paving machines are acceptable if they can place the RCC to the specified thickness and tamping bars are used behind the screed. The suitability and acceptance will be based on the results of the test section.

I. Compaction Equipment:

1. Primary Rollers: Provide single or double drum, self-propelled vibratory rollers that transmit a dynamic impact to the surface through a smooth steel drum by means of revolving weights, eccentric shafts, or other equivalent methods. Use compactors with gross weights of not less than 21,000 lb, minimum dynamic force of at least 475 lb per inch of drum width at the operating frequency used during construction, vibrating frequency of at least 1500 cpm (cycles per minute), drum diameter between 4 and 6 feet, drum width of 5 to 8 feet, and engine horsepower of at least 125. ` Within the range of operational capability of the equipment, variations to the frequency and speed of operation that result in maximum density at the fastest production rate will be allowed. Any other compaction equipment proposed must demonstrate that it is capable of compacting the RCC full depth to the specified density prior to RCC production. Provide at least one fully operable, self-propelled vibratory roller on the placement area at all times during production placement. **[Provide standby replacement equipment available for functional operation on the placement within 30 minutes.]**

The requirement for standby replacement equipment may be omitted unless there is a serious quality concern resulting from a project shutdown.

2. Small Vibratory Rollers: Use small vibratory rollers that can operate within a few inches of a vertical face to compact the RCC adjacent to formwork, precast panels, conventional concrete structures, abutment slopes, and at other areas where the large vibratory rollers specified above cannot maneuver. Provide rollers with a dynamic force of at least 150 lb/in. of drum width for each drum of a double drum unit and at least 300 lb/in. of drum width for a single drum unit. Provide at least one fully operable, small roller at the site during RCC placement. **[Provide standby replacement equipment available for functional operation on the placement within 30 minutes.]**

3. Tampers, Plates, and Rammers: Provide tampers, plates, and rammers that develop a force per blow of at least 3500 lb per square foot. Maintain at least two tampers, plates, or rammers in good operating condition at the site during RCC placement.

PART 3 - EXECUTION

3.01 SCHEDULE AND WEATHER RESTRICTIONS

A. Schedule: It is the intent of this specification to construct the RCC in a continuous operation to the extent practical. Schedule RCC placement **[6 days]** per week **[one 10-hour]** shift per day from the start of placement until completion. Begin placement no later than **[April 15]** and complete by **[June 15]** of the **[same year]**.

Insert placement time limits if required to limit peak temperatures and/or if the owner or local municipality has schedule or regulatory requirements that affect the contractor's production schedule. Insert the appropriate dates, paying attention to local climate conditions. For armoring and overtopping projects, temperature sensitivity is generally not a major concern. The RCC placement window should be wide enough to afford the contractor flexibility. Enough time must be allowed after the Notice-to-Proceed to complete mix designs, prepare foundations, dewater, etc., before the RCC placement window is specified.

B. Cold Weather Concreting: When ambient temperatures fall below 35 °F, institute cold weather concreting procedures as described in Paragraph 3.12.

C. Hot Weather Concreting: Suspend RCC placement when the temperature of the RCC measured at the point of placement exceeds the limits specified in Paragraph 3.08, or if a combination of high ambient temperatures and wind dries the uncompacted RCC, preventing adequate compaction.

In addition to the placement temperature limits specified in Paragraph 3.08, the engineer may also specify a maximum air temperature. However, under most circumstances this is not required.

D. Placing During Precipitation: Do not place RCC during heavy rains (more than 0.2 inch per hour or 0.03 inch in 6 minutes as defined by the U.S. Weather Bureau Glossary of Meteorology). Suspend production when free surface water begins to accumulate on the compacted RCC, when excessive pumping, tracking, or other unacceptable damage begins to develop, or when, in the opinion of the engineer, rain is adversely affecting any aspect of quality. Remove any uncompacted RCC exposed to precipitation that, in the opinion of the engineer, makes it unsuitable.

3.02 FOUNDATION PREPARATION

A. General: Prior to placing roller-compacted concrete on the foundation and against abutments, clean, fill with dental concrete (if necessary), shape (if necessary), and prepare exposed rock surfaces. Do not cover any foundation, embankment slope, or abutment area with any concrete or bedding mix until the area has been approved by the engineer. Place bedding mix as described in Section 2.01 F between the rock foundation or hardened conventional concrete and RCC mixes, except where shown otherwise. No RCC is to be placed in water or on soft foundation material.

For most projects, the engineer should include a separate specification that covers foundation preparation requirements in more detail.

B. Dewatering:

1. Groundwater Control: During the period of RCC preparation and placement, maintain foundations in a dewatered condition. For earth foundation surfaces, install dewatering systems that maintain ground water levels a minimum of 3 feet below the final foundation grade. For rock foundation surfaces, install dewatering systems that prevent ponding and water flowing over rock surfaces.

2. Surface Water Control: Prior to preparing the area for RCC placement, install facilities to divert surface water from the work area. Maintain facilities until all RCC placement and curing are complete.

C. Shaping and Filling Rock Surfaces: Fill depressions as directed by the engineer with conventional dental concrete or roller-compacted concrete. Dental concrete placement areas will be decided by the engineer depending on area access for equipment and thickness of lifts. Dental concrete may require rough face forming, as shown on the drawings. Continuously moist cure dental concrete for **[7 days]** or until covered with additional RCC.

D. Preparation of Earth Slopes and Foundations: Prior to placement of RCC on or against any earth foundation or slope, remove all organics, soft or loose material. Loosen the remaining fill surface by scarifying, plowing, disking, or harrowing to a depth of 4 to 6 inches. Fill all depressions with soil of the same type as the surrounding soil. Adjust the moisture content of the surface as specified for the soil class and compact the foundation or slope to a minimum of **[95%]** Standard Proctor. If allowed to dry, moisten earth slopes and foundations just prior to placing RCC.

Note: For most projects a specification section should be included that describes requirements for testing, placement, compaction, and acceptance of fill materials. For steep slopes greater than 2:1 V scarifying the slope will not be necessary.

E. Final Cleanup: Prior to placing any concrete or bedding mix, clean the surface to remove loose, unkeyed, and deteriorated rock; all mud, silt accumulations, vegetation, grease and spilled oils; frozen materials, standing water, accumulations of gravels, sands and loose rock fragments; laitance that may have accumulated on concrete surfaces; and any other detrimental material. It is expected that most of this can be accomplished with air blowing, high-volume water washing, and/or air/water jetting using equipment normally designed for this purpose and used in large scale foundation cleanups. High performance vacuum systems have also been effective for low areas or pockets in the foundation where water, soil and rock accumulates. A clean sound surface is required. Maintain surfaces upon which RCC or any bedding mix is placed in a damp condition and at a surface temperature in excess of 35 °F. Provide adequate equipment for air, air/water, and/or pressure water washing of the foundation.

3.03 PLANT CALIBRATION AND TESTING

A. Initial Plant Calibration: Certify scales and calibrate plant in accordance with plant manufacturer's written instructions. Prepare and submit certifications and/or calibration report in accordance with requirements of Paragraph 1.04.

B. Mixer Uniformity Testing: Perform mixer uniformity testing if required by Section 2.3.C.3 prior to trial placement to confirm that the mixer and handling and placing procedures meet the specification requirements contained in Table 2-4 and to determine the appropriate mixing time. Placement of RCC in the permanent work will not be permitted until the results of mixer uniformity testing, if required, are submitted to and approved, by the engineer.

C. Recalibration Interval: Perform recalibration of the plant following each **[30 shifts]** or **[15,000 cubic yards]** of placement, whichever comes first, or when quality control testing indicates a potential problem.

3.04 AGGREGATE PRODUCTION, DELIVERY, AND HANDLING

A. General: The requirements of Paragraphs 3.04 B and 3.04 C also applies when RCC is produced off-site and hauled to the project site.

B. Aggregate Production: Operate the aggregate production plant in an efficient manner to achieve and maintain an adequate level of productivity. Ensure that the final aggregate product is consistent and free from contamination by organic material, overburden, or other foreign materials.

The above paragraph and other references to on-site aggregate production may be omitted if aggregates are purchased from a commercial supplier.

C. Environmental Controls:

1. Stormwater Control: Implement work to conform to Best Management Practices for control of site runoff and stormwater pollution for the work area that encompasses the aggregate production plant, stockpiles, and related construction site areas.

2. Pollutant Control: Maintain aggregate plant areas in a clean orderly condition, free from spilled fuel, lubricant, coolant, or other potential pollutants. Maintain material handling areas to reduce potential for pollutants to enter stormwater runoff. Institute special precautions to prevent and to clean up spills of any material that might contaminate stormwater runoff.

A separate specification covering detailed requirements for environmental controls should be included in the bid documents.

D. Delivery:

1. Compliance with Regulations: The contractor's responsibility includes ascertaining and compliance with all state laws and regulations regarding haul vehicle weight limits and other restrictions as they relate to haul vehicles on public

roads. Where the point of ingress or egress is connected to a paved public road, provide a stabilized construction entrance adjacent to the paved area to minimize the amount of mud transported onto the paved area. Maintain the entrance pad and top dress with aggregate as required.

2. Delivery Route: Deliver aggregates using route(s) identified in the approved delivery plan.

3. Maintenance of Roads: Promptly remove, to the satisfaction of the engineer and the haul route's jurisdictional authorities, any soil, aggregate, or other debris deposited on roads or adjacent areas as a result of the contractor's activities associated with the work to be performed under this contract. If the contractor fails to clean a road surface and adjacent areas in a timely manner, or fails to clean the road surface and adjacent areas to the satisfaction of the owner of the road, the owner of the road or the owner has the right to perform the corrective work and charge the contractor for the cost incurred. If the contractor fails to pay the charges, said charges will be deducted by the owner from the contract bid price. **[Perform a pre-haul survey that documents the condition of the haul route prior to initiation of hauling.]**

Include the above requirement for a pre-haul route survey in cases where substantial hauling is required or where damage or claims of damage might occur.

Notify the engineer as soon as any damage or deterioration to the road(s) occur that is likely to require remedial work.

4. Delivery Schedule: Within **[14 days]** after Award of Contract, prepare and submit to the engineer for approval a production and delivery schedule for the RCC aggregates. Limit delivery times to between **[6:00 a.m. to 6:00 p.m., Monday through Saturday]**. **[Unless otherwise permitted by the owner, no Sunday delivery will be permitted. Requests for delivering RCC aggregates on Sunday must be submitted to the owner for approval.]**

Insert delivery days and hours as appropriate for the local municipality and requirements of the owner's schedule. Depending on the difficulty of the project and the required RCC placement schedule, extended times for aggregate delivery may be necessary.

E. Stockpiling Procedures: Stockpile aggregate at the project site within the boundaries designated on the plans. Establish precise limits of the piles as necessary to accomplish the work. Use separators, if necessary, such as timbers or boards between adjacent stockpiles to prevent contamination and intermixing between the stockpiles.

Prepare the lane and the base of the aggregate stockpile by removing all organic material, flattening the area, filling any major depressions, and sloping the surface of the stockpile bases and the lane area to drain. **[Provide a base of free draining gravel or crushed rock, or allow for a sacrificial layer of material within the stockpile area. If used, the base material may have a maximum size up to 4 inches, not more than 10% passing the 3/4-inch sieve, and not more than 2% passing the No. 50 sieve.]**

In dry climates, a free draining stockpile base may be unnecessary. In these cases, the above requirement may be omitted.

Construct stockpiles by an approved method that reliably and consistently stores the aggregates and later allows their withdrawal from the stockpiles without contamination or segregation. Provide a system that permits intermixing or blending of aggregates as they are delivered and spread in the stockpiles.

F. Moisture Conditioning: If aggregate evaporative cooling is utilized, or if products are sufficiently dry to require moisture conditioning, continuously mist aggregates during stockpiling to a saturated surface-dry (SSD) condition. Use sprinklers or fog spray type and do not apply pressurized water directly into stockpile. Exercise caution during aggregate stockpile misting to prevent washing of fine material.

G. Stockpile Withdrawal: Withdraw aggregates from the stockpiles using conveyors, face loading with front-end loaders, or a combination of conveyors and face loading. Regardless of the method employed, withdraw materials that are representative of the entire stockpile, both in terms of gradation and moisture content. Blend any obviously segregated material with other material in a manner that will result in a gradation that meets the specifications. If the material cannot be suitably blended, separate it from the stockpile and use for other non-critical purposes, or waste the material.

Note: Face loading with front-end loaders is usually sufficient for the majority of embankment armoring and spillway projects.

3.05 TRIAL PLACEMENT

A. Purpose: The contractor should anticipate that at least **[one full day]** may be required to complete the goals of the trial placement. The contractor is encouraged to expand the trial placement as necessary to demonstrate his ability to meet the specifications prior to proceeding with production placement.

Two or more days are sometimes used for the test section to simulate cold joints, cold joint treatments, or other items that require an extended waiting period.

B. Location: Construct the trial placement at a designated on-site location and in accordance with the details shown on the drawings.

Sometimes the test section can be a part of the permanent structure if located in a non-critical area and the RCC properties meet the specifications.

C. Equipment and Placing Procedures: Demonstrate during the trial placement the intended construction techniques and materials to be used in construction of the structure. Tasks to be included are **[facing elements], [lift-surface cleaning], [compaction], [density testing], [cold joints], [bedding-mix placement],** and **[forming and/or shaping of steps and training walls].** The supervisory and key craft personnel intended to perform the production placement must be involved in construction of the trial placement. Do not initiate the trial placement until the plant and all equipment required for delivery and placement of RCC are operational and fully calibrated. Perform mixer uniformity testing, if required by Section 2.03.C, prior to initiating trial placement. Trial placement for the test section will not be permitted until the results on the uniformity testing, if required by Section 2.03.C, are provided to the engineer in writing and such test results demonstrate that the plant meets the specification requirements. Place a minimum of **[100 cubic yards and three 12-inch-thick lifts] [20 feet wide by 50 feet long with three lifts]** in the trial placement. Place bedding mix, if required, on a minimum of two lifts as shown on the drawings. Anticipate and allow for numerous stops/restarts during the trial placement so that the engineer may perform testing of the RCC. Demonstrate various spreading and compaction procedures including, but not limited to, various equipment types, and numbers of passes. Construct the trial placement just prior to production placement of RCC.

Place any other items to be demonstrated at the test section in this paragraph.

D. Testing and Quality Control: Prior to initiating the trial placement, perform testing of the aggregates in accordance with the requirements of Paragraph 3.16 to demonstrate that specification requirements are met. Perform all other tests and quality control measures identified in Paragraph 3.16 during the trial placement. In addition, the engineer will perform his own tests and inspections and the contractor should anticipate interruptions to his work to accommodate such tests and inspections. Allow **[7 days]** from the completion of the trial section until production can begin so the engineer can perform his evaluation of the test section.

If the engineer does not plan on any strength testing of the RCC in the test section, the [7 day] requirement can be eliminated.

E. Critique: The engineer and contractor will closely monitor activities during construction of the trial placement and provide an informal critique and review session for all involved, including supervision, inspection, engineering, and craft personnel, prior to RCC placement in the structure.

3.06 MIXING

A. Cement and Aggregate Feed: Feed cement and aggregates uniformly, continuously, and simultaneously, at the appropriate ratios for the mix design specified, into the mixer by belt or other acceptable method. Feed controls may be by volume or weight. Aggregate feed may be accomplished by a single belt from each stockpile or from feed bins of the various size groups through openings at the bottom of the feed bins. Provide each opening in aggregate feeders with a gate that can be locked at the necessary opening size to provide the correct feed rate. Keep return side of all belts clean. Keep bins sufficiently full to allow a uniform flow of aggregate at an essentially constant rate. Particular attention may be needed to guarantee a continuous flow of the fine aggregate if it is very damp and is graded towards the fine side of the specified gradation band. Feed cement (and pozzolan if used) continuously in a manner that can be controlled by adjusting the belt speed or feed rate. Provide special attention to the cement (and pozzolan if used) feed equipment so that it consistently and uniformly delivers materials even at low (100 lb/yd^3 or less) dosage rates. Use feeds capable of gradual adjustment while in operation. Use continuously correcting automated gate openings and/or belt-feed rates by electronic feedback of weight sensor units on the belts if operation without them cannot provide the accuracy, consistency, and quality required by these specifications.

B. Operation: The intent is to operate continuous pugmills in a continuous manner at one set of feed rates with a minimum number of shutdowns and startups during RCC production placing. Calibrate and operate the plant so that all materials simultaneously begin feeding into the mixer at the correct rates when the mixer is started, and all materials simultaneously stop feeding into the mixer when it is stopped. No lag or lead time between materials will be allowed at the point where they enter the mixer. After material feeds are shut down, discharge all remaining material in the mixer. The initial RCC produced after a plant re-start may not conform to the specification requirements. If the plant can be stopped and re--started at the same mix proportions, no material has to be wasted. The need to waste material after a restart will be evaluated for consistency and uniformity on a case-by-case basis by the engineer. When the plant is shut down for over **[30 minutes]**, waste the first cubic yard of material. **[See Commentary for additional discussion]**.

C. Accuracy: Proportion RCC discharged from the mixing plant within the tolerances shown in Table 3-1.

Table 3-1: Allowable Tolerances of Mixing Plant

Material	Accuracy limit (%)
Pozzolan (if used)	Plus or minus 2%
Cement	Plus or minus 2%
Water	Plus or minus 3%
Aggregate	Plus or minus 3%
Admixture	Plus or minus 3%

3.07 CONVEYING AND TRANSPORTING

A. General: Convey RCC from mixer to placement as rapidly as practicable, by methods that control segregation, contamination, and drying. If necessary, provide baffles at the end of conveyors and within hoppers to limit free falls, and at other locations that otherwise cause excessive segregation. Equipment will not be allowed to track mud or other contamination onto previously placed RCC. This may require using clean crushed rock on haul roads, washing tires of vehicles prior to driving onto the RCC, and other special measures. Any contamination on the RCC must be cleaned from the RCC prior to placing the next lift. The time from mixing to spreading the RCC must not exceed **[30 minutes]**.

B. Temporary Storage Containers: Provide interim storage at gob hoppers (such as at a central dispatch point on the dam) when vehicles are used for hauling, and when direct conveyor systems do not otherwise provide continuous unsegregated delivery to the final placement location. Use gob hoppers constructed with side slopes and gates that allow for the free flow of RCC without segregation or choking. Provide telephone or radio communication between gob hoppers, the mixing plant, and the placement site. If more than one RCC mix is used, completely empty gob hoppers before filling with a mix of a different design.

C. Conveyors and Haul Vehicles: RCC may be delivered to the placement area by either conveyors or haul vehicles or a combination of both, or by other methods if approved in advance by the engineer.

Note: Specific project requirements may dictate that one particular delivery method is preferred because of site access, weather, or quality requirement. In that case, the design engineer may prohibit one of the delivery methods specified below.

1. Haul Vehicle Delivery: Haul vehicles will not be permitted to travel on and off any lift surface without precautions to prevent contamination of the RCC. Remove by hand or reblend during spreading any segregation that results from using haul vehicles. Maintain hauling vehicles in good operating condition and prevent oil, grease, or other visible and obvious contamination to spill or drip onto the RCC. Operate haul vehicles in a manner that precludes tight turns, sudden stops, or other procedures that damage previously compacted RCC. If a surface is damaged by vehicle operation (tight turns, oil spills, etc.), clean the damaged surface or remove the damaged material. Haul vehicles must meet the requirement of Section 2.03.E.
2. Conveyor Delivery: Conveyor belt delivery is required for all RCC delivered from the concrete plant to the point of final placement. The only RCC that will be considered for truck delivery to the placement area or active lift surface will be any trial placement or practice areas. Operate belts at speeds that meet production requirements and do not segregate materials.

Note: Experience has shown that conventional end dumps have a tendency to cause segregation at the edge of the deposited material. Drier mixes, mixes with a low sand content, and mixes with maximum size aggregate larger than 1-1/2 inch have the greatest tendency for segregation. If the designer plans to use a mix with these characteristics, consideration should be given to restricting use of end-dump trucks.

3.08 PLACING AND SPREADING

A. General: The contractor is cautioned to understand and apply applicable fall protection requirements to all work on the site. The contractor is responsible for all health and safety requirements at the site.

B. Temperature Restrictions: Do not place RCC when ambient temperatures drops below 32 °F, unless the surface of the compacted RCC and the temperature of the RCC mix stays above 35 °F. In that case, placing of RCC during temporary periods will be permitted if the ambient temperature remains above **[25 °F]**. If the ambient temperature drops below 32 °F or the surface of any RCC less than 7 days old drops to 35 °F, cover the surface with heavy tarps, blankets, straw, or other acceptable temporary protection until the ambient temperature rises above 35 °F. Remove RCC that is less than 7 days old and is exposed to temperatures less than 32 °F.

   Place all RCC at a material temperature of **[80 °F]** or less. The temperature will be measured at the point where the RCC is delivered to the lift surface. Introduction of chilled water in the mix, cooling the coarse aggregate with chilled water, placement at night, spraying the coarse aggregate stockpile with chilled water, cooling material by injection with liquid nitrogen, or other approved measures will be required when this temperature restriction cannot be met by normal placement procedures.

Note: Insert maximum placing temperatures as appropriate considering the annual average temperature at the site. Higher maximum RCC placing temperatures can be tolerated in warmer climates. If conditions are such that the in-place temperature of the RCC is not a concern, the preceding paragraph may be eliminated. However, experience has demonstrated that some temperature controls are usually necessary to prevent unacceptable cracking of the RCC.

C. Layout of the Placement Area: It is the intent of this specification to raise the RCC at essentially the same level across its entire area. As nearly as is practical, expose no more than two lift surfaces at one time. One additional layer may be exposed under special circumstances such as crossing conduits or other features. Maintain lift grade control by using grade stakes and/or laser-guided equipment, or other surveying methods. As placement of a lift progresses keep the exposed edges "live" by progressively placing out from them. Whenever a cold joint at any edge of any lift occurs, locate it at least 10 feet from the location of other cold joints that may have previously occurred in the same direction. Prepare the joint as required by Section 3.10 of these specifications for "cold joints" prior to resumption of RCC placement.

D. Depositing: Deposit RCC at the location at which it is to be spread. Where haul vehicle delivery is used, depositing will generally be accomplished with a dump-spread action while the vehicle is moving. When stationary end dumping is necessary, deposit the material on top of the fresh RCC layer being advanced, not on the previously compacted layer. Do not place material in piles higher than 5 feet. For belt delivery, limit pile heights and discharge from the belts in a manner that does not cause segregation. If trucks are used to deliver RCC, do not discharge material directly against any formwork. At isolated or confined placement locations, the engineer may permit pushing the RCC up to **[50 feet]** with spreading equipment, provided that segregation does not occur. Modify operations if excessive segregation is occurring.

Note: Experience has shown that wet mixes with a high sand content and 1-1/2-inch maximum size aggregate can be pushed 50 feet or more without noticeable segregation. The segregation potential increases significantly for drier mixes, with lower sand contents and larger aggregate. The designer should consider the RCC mix when selecting an allowable limit for pushing RCC.

E. Lift Thickness: Unless another lift thickness is satisfactorily demonstrated and approved during the trial placement construction, place RCC in **[12-inch]** lifts as measured after compaction. Do not place RCC in compacted lifts less than 4 inches thick.

F. Spreading: Within 10 minutes of deposition, knock down and spread the RCC pile using a tracked dozer or other approved spreading equipment. Spread material so that it is placed in unsegregated layers that will result in a compacted lift with a thickness of approximately **[12 inches]** and within the tolerances specified in Paragraph 3.15. Where RCC is spread onto or into bedding mix, spread and compact the RCC mix within 90 minutes of the time the bedding mix was batched, prior to the time that it begins to set or dry from exposure, and within 45 minutes of when the bedding mix was first deposited. Do not operate tracked spreading equipment on compacted RCC unless tracks with flat rubber pads are used or rubber mats are placed between the compacted surface and the dozer tracks. Remove any loose material resulting from operation of equipment on compacted surfaces prior to placing the next lift. Have a front-end loader with operator available to assist with depositing and spreading of material in confined areas, at irregular foundation conditions, and at other locations as needed. Accomplish spreading in a manner that does not cause segregation. If large aggregate rolls or segregates to the outside edge of a spread layer of RCC, reblend it into the RCC or remove it. Maintain all equipment in good operating condition so that it does not leak or drip oil, grease, or other obvious visible contamination onto the RCC. Do not place concrete on a previous layer which is suspect and is being considered for testing, retesting, or rejection.

RCC may be placed with an approved paver. Adjust the paver and regulate the speed to prevent segregation. Do not exceed a paver speed of 10 feet per minute unless it can be demonstrated to the satisfaction of the engineer that higher speeds do not cause problems. Operate the paver with a constant supply of RCC in the hopper.

Experience has shown that segregation may occur when the mix becomes drier than desired and/or when care is not used during dumping and spreading. Large aggregate that rolls to the outside edge of a spread layer can be picked up by laborers with flat shovels and broadcast over the uncompacted surface in order to be compacted into the RCC without segregation.

3.09 COMPACTION

A. Determination of Optimum Compaction Density Value: The engineer will determine the optimum compaction density value during the trial placement. The value will be established after evaluation of density results obtained with a nuclear density gauge and evaluation of the compaction characteristics for each mix design. Final evaluation of density results for the determination of the optimum compaction density value will be made only after all major field adjustments have been made and the mix design is considered to represent RCC that has suitable placement, spreading, and compaction characteristics, and provides the required strength and porosity values. Small field adjustments to the optimum compaction density value will be made throughout construction based upon the running average density value. Such changes may be made based on slight changes or long-term drift of density values resulting from field mix design adjustments.

See Commentary for method of determining optimum compaction density value.

B. Compaction: Within **[45 minutes]** of water being introduced at the mixing plant, compact each layer of RCC with a minimum of **[4]** passes of a self-propelled double drum or **[8]** passes of a self-propelled, single-drum vibratory compactor. (A round trip is 2 passes). Use the largest size equipment specified below that is capable of physical and practical operation in the area to be compacted. Use large width self-propelled vibratory rollers in open areas with a minimum of 4 vibratory passes on each lift. Use small walk-behind vibratory rollers and/or hand-guided power tampers for compaction at the abutments and in any areas that cannot be reached with the drum of a large vibratory roller. Do not operate rollers in the vibratory mode until they are moving. Maintain all compaction equipment in good operating condition at all times and do not allow it to drip or spill oil or other obvious visible contamination onto the RCC. Break down, trim, and compact the edge of all compacted layers against which adjacent RCC is not placed within **[30 minutes]** so that the edge is thoroughly compacted and does not contain loose segregated aggregate. Spread and roll so that a flat surface results with minimum roller marks from the edge of the drum, and so that the drum does not bridge over any of the surface beneath the roller drum after the last pass. Operate rollers at speeds not exceeding 160 feet per minute.

C. Acceptance: The running average of **[5]** consecutive in-place density tests should not be less than 98% of the optimum compaction density value, with no individual test less than 96%. Determine the average wet density from the average of two readings taken with the gauge probe at a depth equal to the thichness of the lift. If the two readings vary by more than 2%, repeat the density test. If it is demonstrated early in production that the two readings are consistently within 2%, the two readings can be discontinued. Also measure densities with the gauge probe at 4 inches and 8 inches; however, these readings will not be used to compute the average density.

See Commentary for alternative methods of determining the required density.

D. Additional Compaction: If, after testing, the RCC does not meet the required density, it may be compacted with additional roller passes, provided that the time limit in Paragraph 3.07A has not been exceeded.

E. Removal of Material: If the time limit specified in Paragraph 3.07A has been exceeded and the RCC has not achieved the required density, remove the RCC and replace at no cost to the owner. Clean the underlying surface and treat as a lift surface cold joint prior to replacing the removed RCC with new material.

F. Exposed Edge Compaction: Where lift edges are permanently exposed, compact or purposely overbuild edges to allow for trimming back to well-compacted RCC, meeting the design lines and grades. Edge compaction may be by excavator mounted vibratory compaction plates, or other means approved during the trial placement construction. Trimming may be performed manually or with mechanical equipment. The minimum density of unformed edges must be 95%.

3.10 LIFT AND CONTRACTION JOINTS

A. General: It is the intent of this specification to place the entire RCC mass with sufficient continuity so that it hardens and acts as one monolithic block (between contraction joints) without discontinuous joints or potential planes of separation. The length of time between placement of successive layers of RCC that can be tolerated is dependent upon temperature. Joint quality is also dependent upon cleanliness and surface moisture. When the limits between successive lifts of RCC layers exceed those specified herein, a cold joint will be considered to have occurred, and the procedures described for cold joints in Paragraphs 3.10C and D shall be followed.

B. Routine Lift Surface Treatment: Keep joint surfaces in a clean, uncontaminated, and continuously moist condition until placement of the succeeding concrete. At a minimum, the contractor should anticipate blowing every lift surface with compressed air if loose material and contamination are present. Employ a system to continuously maintain lift surfaces in a moist, but not wet, condition. The system may consist of, or be supplemented as necessary by, mists and light sprays from hand-held hoses to reach all areas of each lift. Heavy sprays from water trucks provide too much water and are not acceptable. Water trucks may be used if they can provide a fine spray or mist. Do not apply the mist or spray in a channeled or pressurized manner that erodes the fresh RCC surface or at a rate that causes ponding on the surface. Have at least one person on duty during RCC placement operations with the sole responsibility of operating the water system to keep the entire surface moist but not over-watered. He may be allowed to perform routine maintenance of nozzles and move hoses only if these activities do not prevent him from keeping the entire exposed surface in a continuously damp condition. During non-placement hours the RCC must be maintained in a moist condition either by on-site personnel or by covering the lift with tarps or plastic.

C. Lift Surface Cold Joints: A cold joint on a lift surface will be considered to have occurred when more than **[1000 degree-hours (F)]** have elapsed before placement of the successive lift. Determine degree-hours by accumulating the average temperature in degrees Fahrenheit at the lift surface during each one-hour increment after the surface has been compacted. Use a continuous clock-type temperature recording device, such as that manufactured by Forney Inc., Wampum, Pennsylvania, model number LA-0546-50, or equivalent, for determining and recording the time and temperatures. Prepare cold joints for the subsequent lift by removing all laitance, loose debris, and contaminants from the entire surface. Expose, but do not undercut the aggregate with the cleaning procedure. At this stage of maturity, use water jetting if air alone does not satisfactorily prepare the surface. After preparation, maintain the surface in a damp condition and place a layer of bedding mix with an average thickness as shown on the drawings over the lift surface.

Note: The selection of the appropriate "degree-hours" limit will depend on the design requirements for the projects. In general, the definition of a cold joint has ranged from 500 degree-hours to 2,000 degree-hours (F).

*In lieu of monitoring degree-hours a certain time limit of [**4 hours**] may be used to define a cold joint. See Commentary for discussion.*

The requirement for bedding mix is project specific. If no cohesion is required at lift joints, bedding mix may not be required. See Commentary for discussion.

D. Lift Edge Cold Joints: A cold joint on a lift edge will be considered to have occurred when more than **[30 minutes]** has elapsed since placement of the material at the lift edge. Treat cold joints by trimming back the edge to compacted RCC a minimum of 9 inches on a 1H: 1V slope prior to resuming RCC placement.

E. Contraction Joints (Vertical Joints): Construct contraction joints at the locations and alignment shown on the drawings. Any joint started at the foundation of the RCC must be continued to the full height of the placement. The joint details shown on the drawings may be modified only with prior approval by the engineer. The locations of several joints may be adjusted depending on foundation conditions encountered.

For RCC placed on rock, foundation conditions often determine the location and number of contraction joints. If it is anticipated that the number of joints may change, an estimated number of joints potentially added or deleted should be inserted in the last sentence of the preceding paragraph. If no changes are anticipated, this paragraph can be omitted.

3.11 REINFORCING STEEL AND ANCHOR BARS

A. General: Meet the requirements of **[Section on Reinforcing Steel and Anchor Bars]** if used in the RCC, except modify placement as described herein.

B. Anchor Bars: Install in accordance with the requirements of **[Section on Drilled and Grouted Anchor Bars]**.

C. Reinforcing Steel: Locate reinforcing steel, and anchor bars so that not less than a 2-inch nor more than a 5-inch clear distance exists between the bar and the surface of the RCC below it.

3.12 CURING AND PROTECTION

A. Cold Weather Protection: Keep the surface of all RCC lift layers continuously damp and at a temperature above 35 °F until it is covered with the next layer of **[RCC], [conventional concrete], [earthfill]**, or **[asphalt],** or until an age of

[14 days] has been reached. Comply with the temperature restrictions in Section 3.08.B. Measure the RCC temperature with a digital thermometer equipped with a surface probe.

B. Moist Curing Requirements: Keep the surface of all RCC lift layers continuously damp until each is covered by the next layer or for a period of **[14 days]**.

C. Erosion Protection: Protect from erosion by heavy rain and damage by water trucks all surfaces of RCC layers upon which subsequent layers will be placed. Clean any surface damaged by erosion that undercuts coarse aggregates, and cover with bedding mix prior to placing next RCC layer.

Insert required number of days for cure period in paragraphs A and B

D. Use of Curing Compounds: Curing compounds will not be permitted on the RCC.

3.13 FACING FINISH TREATMENT

Several types of RCC facing treatments are available. A brief discussion of the different types of facing systems available, along with a discussion of the merits and general guidelines for selecting a facing system, are presented in the Guide Specification Commentary. In the specification paragraphs that follow, six different types of facing treatments are discussed. The designer should use only the paragraphs that apply to the facing treatment(s) proposed for the project. RCC has very good erosion resistance if compacted to specified densities. Special facings are only typically used in the most severe climates, frequent flow events, and where esthetics is an important consideration.

A. Forming: Construct the treatment(s) for the exposed face of the RCC as shown on the drawings and specified herein. Select a forming system and demonstrate at the RCC test section that it will provide RCC surfaces within the specified tolerances.

B. Unformed RCC:
   1. Shaping and Cleanup of Exposed Face: During construction, routinely trim the unformed face with hand tools or other approved method to provide a relatively uniform and moderate-to-well compacted surface. Perform trimming in such a manner as to prevent removing material beyond the neat lines shown on the drawings and damage to surface and interior RCC. During or after RCC construction, remove any protrusions or obvious major discontinuities that may exist. **[Then clean the exposed RCC surface with a high-pressure water jet of not less than 3000 psi].** Remove loose gravel or buildup at the toe of the RCC slope that is not advantageous from an aesthetic and/or drainage standpoint as directed by the engineer. Acceptance of the project by the owner will not occur until all slopes and steps are clean of all accumulation of loose RCC. Material removed may not be reused within the RCC structure.

For constructability, the downstream sloped face of the RCC armoring should generally be flatter than 0.80H to 1V. Steeper slopes require downstream forms to maintain the slope as the natural angle of repose of the RCC mix is exceeded.

For most applications, pressure washing of the completed slope is unnecessary. However, for projects with significant public visibility, pressure washing of the completed slope may be considered. Removing all loose material at completion of the project perm its visual observation of future weathering.

2. Compaction: Compact RCC as specified in Paragraph 3.09 to the outer edge of the lift. **[Compaction of the downstream sloped surface of the RCC lift is not necessary].**

   or

   [Compact the outer edge slope of the lift using rubber tired equipment to wheel-roll the edge, a "whacker" type tamper, vibratory plate compactor mounted on a rubber-tired backhoe, pole tamper, or other approved method].

See Commentary for discussion of unformed sloping steps and training walls, compaction, trimming, overbuild, etc.

3. Tolerances: Construction tolerances for the exposed face are as follows:
   a. During placement, limit gradual overbuild of the exposed downstream face to **[1 foot].** Underbuild will not be allowed.
   b. After trimming and cleaning, limit gradual overbuild of the exposed RCC face to **[0.5 foot]**. Underbuild will not be allowed.
   c. Do not exceed **[3 inches in 50 feet]** variation in any unformed exposed RCC surface after trimming and cleaning as measured in a straight line along the length and width of the face, nor **[6 inches]** over the entire length and height of the dam. Clean any untrimmed surface that has been allowed to harden, and remove any objectionable protrusions.
   d. Do not vary the upstream and downstream edges of the finished top of the RCC overtopping protection by more than **[1 inch in 10 feet]**. Do not exceed the plan width by more than **[6 inches]**. Place the top lift such that the final elevation of the top RCC layer is within **[2 inches]** of that shown on the drawings and does not vary more than **[1 inch in 10 feet]**. Underbuild will not be allowed.

Appropriate tolerances will vary from project to project and on the type of facing specified. Average values are included herein. For projects in remote locations, or those where the RCC slope will be covered with either rock or earth fill, the tolerances may be relaxed.

C. Formed RCC:
1. Forms: Form the steps and any other exposed RCC face to provide the finished surfaces shown on the drawings. Construct all formwork as specified in **[Section on Concrete Formwork].** The contractor is responsible for the design of the formwork, as well as its construction. Provide and construct forms with sufficient strength to withstand the pressure resulting from placement and compaction of the RCC and with sufficient rigidity to maintain specified tolerances. Forms need not be mortar tight if bedding mix is not used.
2. Bedding Mix: Place bedding mix against the bottom of the form prior to placing and compacting RCC. Place and spread the RCC against the forms in a manner that causes the bedding mix to ride up the face of the form. Adjust the amount of bedding mix and method of RCC placement and compaction to eliminate air pockets and other causes of honeycombing, pitting, or planes of weakness in the exposed, formed surface.

The need for bedding mix will depend on the workability of the RCC mix and/or desired appearance of the vertical step faces. If appearance is not a concern, and/or a highly workable RCC mix is used, the requirement for bedding mix may be omitted from the specification.

3. Repairs: It is the intent of these specifications to require forms and RCC workmanship be such that RCC surfaces will require no repairs after form removal. As soon as the forms have been stripped and the formed surfaces exposed, the engineer will inspect the formed surface to determine if there is adequate consolidation, excessive honeycomb, or other defects. If the defects are excessive, clean the defective areas of loose or unconsolidated material and repair with conventional concrete at no cost to the owner as specified in **[Section on Cast-In-Place-Concrete]**.

4. Compaction: Compact the RCC as specified in Paragraph 3.09.
5. Tolerances: Construction tolerances for the formed exposed face are as follows:
   a. Limit gradual overbuild in any horizontal direction of the formed face to **[4 inches]**. Underbuild will not be allowed.
   b. Do not exceed **[1 inch in 10 feet]** or **[3 inches in 100 feet]** variation in any formed, exposed RCC surface as measured in a straight line along the length of the formed surface.
   c. Do not vary the upstream and downstream edges of the finished top of the RCC overtopping protection by more than **[1 inch in 10 feet]**. Do not exceed the plan width by more than **[6 inches]**. Place the top lift such that the final elevation of the top RCC layer is within **[2 inches]** of that shown on the drawings and does not vary more than **[1 inch in 10 feet]**. Underbuild will not be allowed.

D. RCC with Precast Panel Face

The specification for "RCC with Precast Panel Face" is intended to cover the requirements for RCC placement as it relates to this facing system. Additional specifications should be provided by the designer to address the precast panel system including specifications for: Precast Concrete Panel Fabrication, and Precast Concrete Panel Installation.

1. Surface Preparation: Prior to placing RCC against the precast panel, inspect the surface of the precast panel against which the RCC will be compacted for alignment, cracks, and other defects. Do not place bedding mix or RCC against a precast panel until the panel has been accepted by the engineer.
2. Bedding Mix: Place bedding mix against the bottom of the panel prior to placing and compacting the RCC. Place and spread the RCC against the panels in a manner that causes the bedding mix to ride up the face of the panel.

The use of bedding mix is not always necessary. If bedding mix is used over the RCC surface before placing a subsequent lift to enhance bonding between lifts, item 2 above— Bedding Mix—should be specified.

3. Panel Alignment Control: Routinely check panel alignment to prevent excessive panel "growth" due to over-shimming, or "shrinkage" due to under-shimming, in either the vertical or horizontal dimensions. Maintain the horizontal alignment within **[2 inches in 50 feet]** of length, but not to exceed **[3 inches]** overall. Maintain the vertical alignment within **[2 inches in 40 feet]** of height. The top row of panels will be held to a stricter tolerance: vertically within **[1/4 inch]** of the adjacent panel, and not to exceed **[1 inch]** from the top of dam design elevation, and horizontally within **[1 inch in 100 feet]**, but not to exceed **[2 inches]** overall. Do not cut the top row of panels to meet the required vertical alignment.
4. Compaction: Compact the RCC as specified in Paragraph 3.09.
5. RCC Tolerances at the Top Lift: Do not vary the upstream and downstream edges of the finished top of the RCC over topping protection by more than **[1 inch in 10 feet]**. Do not exceed the plan width by more than **[6 inches]**. Place the top lift such that the final elevation of the top RCC layer is within **[2 inches]** of that shown on the drawings and does not vary more than **[1 inch in 10 feet]**. Underbuild will not be allowed.

E. RCC with Conventional Concrete Face:

The specification for "RCC with Precast Conventional Concrete Face" is intended to cover the requirements for RCC placement as it relates to this facing system. Additional specifications should be provided by the designer to address conventional concrete placement.

1. Forms: Form the steps and any other exposed concrete face to provide the finished surfaces shown on the drawings. Construct all formwork in accordance with **[Section on Concrete Formwork]**. The contractor is responsible for the design of the formwork, as well as its construction. Provide and construct forms with sufficient strength to withstand the pressure resulting from placement and consolidation of the concrete, and with sufficient rigidity to maintain specified tolerances.

2. Concrete: Use concrete for the conventional concrete face that conforms to applicable requirements of **[Section on Cast-In-Place Concrete].**

3. Placement of RCC and Conventional Concrete: Place RCC and the conventional concrete face as shown on the drawings and approved during trial placement. Use immersion vibrators to thoroughly consolidate the interface between the conventional concrete and RCC.

On the drawings, the designer may want to include chamfers or other rustications at horizontal cold joints in the formwork so that the concrete cold joints are not visible. This is not necessary if slip forming is used.
A consensus has not been reached with regard to the sequence of placement of conventional concrete and RCC at the downstream face. The contractor should be required to demonstrate the proposed method of constructing the downstream face as part of the trial placement testing. The objective is to obtain consolidation of the RCC and facing concrete to provide a monolithic joint at the interface.

4. Repairs: It is the intent of these specifications to require forms and RCC and conventional concrete workmanship be such that finished surfaces will require no repairs. Take extreme care to prevent any defects in the formed surface. As soon as the forms have been stripped and the formed surfaces exposed, the engineer will inspect the formed surfaced to determine if there is adequate consolidation, excessive honeycomb, or other defects. If the defects are excessive, clean the defective areas of loose or unconsolidated material and repair with conventional concrete at no cost to the owner as specified in [Section on Cast-In-Place-Concrete].
5. Compaction: Compact the RCC as specified in Paragraph 3.09. Compaction of the sloped surface of the RCC lift is not necessary.

The RCC sloped surface that conventional concrete will be immediately placed against should not be compacted.

6. Tolerances: Construction tolerances for the exposed face are as follows:

   a. Limit gradual overbuild in any horizontal direction of the formed face to **[6 inches]**. Underbuild will not be allowed.
   b. Do not exceed **[1 inch in 10 feet]**, or **[3 inches in 100 feet]** variation in any formed, exposed surface as measured in a straight line along the length of the formed surface.
   c. Do not vary the upstream and downstream edges of the finished top of the RCC overtopping protection by more than **[1 inch in 10 feet].** Do not exceed the plan width by more than **[6 inches]**. Place the top lift such that the final elevation of the top RCC layer is within **[2 inches]** of that shown on the drawings and does not vary more than **[1 inch in 10 feet]**. Underbuild will not be allowed.

F. RCC with Reinforced Concrete Face:

The specifications for "RCC with Reinforced Concrete Face" are intended to cover the requirements for RCC placement as it relates to this facing system. Additional specifications should be provided by the designer to address the reinforced concrete placement. In addition, for constructability, the downstream sloped face of the RCC should generally be flatter than 0.8H to1 V if RCC is placed unformed. Steeper slopes require downstream forms to maintain the slope as the natural angle of repose of the RCC mix is exceeded.

1. Shaping and Cleanup of RCC Face Prior to Placing Reinforced Conventional Concrete Face: During construction, spillage over the downstream face is expected to occur, which will result in an accumulation of loose, uncompacted RCC at the face and along the toe. It will probably have little or no cemented value. During construction, routinely trim the unformed face with hand tools or other approved methods to provide a relatively uniform and moderate to well compacted surface. Perform trimming in such a manner as to prevent damage to surface and interior RCC. During or after RCC construction, clean any unformed face of protrusions and obvious major discontinuities that may exist. Then clean the exposed RCC face with a high-pressure water jet of not less than 3000 psi. Remove loose gravel or buildup at the toe of the RCC slope that is not advantageous from an aesthetic and/or drainage standpoint as directed by the engineer. Suitable material removed during construction may be used for haul roads or the contractor's convenience, but do not reuse or place such material within the RCC mass.
2. Compaction: Compact the RCC as specified in Paragraph 3.09. Compaction of the downstream sloped surface of the RCC lift is not necessary and will not be allowed.
3. Tolerances: Construction tolerances for the RCC face before placement of the reinforced concrete facing are as follows:
   a. During placement, limit gradual overbuild of the exposed downstream face to **[1 foot].** Underbuild will not be allowed.
   b. After trimming and cleaning, limit the gradual overbuild of the exposed RCC face to **[0.5 foot]**. Underbuild will not be allowed.
   c. Do not exceed **[3 inches in 50 feet]** variation in any unformed exposed RCC surface after trimming and cleaning as measured in a straight line along the length and width of the face, nor **[6 inches]** over the entire length and height of the dam. Clean any untrimmed surface that has been allowed to harden, and remove any objectionable protrusions.
4. Tolerances for Finished Construction: Do not vary the upstream and downstream edges of the finished top of the RCC overtopping protection by more than **[1 inch in 10 feet]**. Do not exceed the plan width by more than **[6 inches]**. Place the top lift such that the final elevation of the top RCC layer is within **[2 inches]** of that shown on the drawings and does not vary more than **[1 inch in 10 feet].** Underbuild will not be allowed.

G. RCC Placed Concurrently with Fill Material:

1. Placement of RCC and Fill Material: Place RCC and fill material as shown on the drawings and approved during trial placement. Prevent contamination of the RCC lift with fill material. Keep all fill material outside the RCC payment line. Limit ingress and egress onto the lift surfaces and prevent contamination of the lift surface. Remove any lift contamination prior to the next lift.
2. Compaction: Compact the RCC as specified in Paragraph 3.09. Compaction of the downstream sloped surface of the RCC lift is not necessary if a minimum of 1 foot overbuild is used. If the overbuild is less than 1 foot the surface must be compacted.
3. Tolerances: Construction tolerances for the buried face are as follows:
   a. Overbuild tolerances are specified in Paragraph 3.13 G.2. above. Underbuild will not be allowed.

3.14 INSTRUMENTATION

A. General: Install as specified in **[Section on Instrumentation].** The locations and types of instrumentation are shown on the drawings but may be modified as the job progresses. Have all instrumentation available in sufficient time to be installed at its desired location without delaying construction progress.

3.15 STRUCTURAL TOLERANCES

A. General: Construct within the tolerances specified in **[Section on Concrete Formwork]**, except as supplemented or modified below. Additionally, tolerances shown below may be superseded by tolerances specified in Paragraph 3.13, Facing Finish Treatment.

B. Specific Requirements:

1. Limit gradual overbuild of the downstream face of the RCC to **[0.5 foot]**. Underbuild will not be allowed.
2. Do not vary the downstream edge of any RCC lift by more than **[3 inches in 200 feet]**.
3. Construct the thickness of individual compacted layers of RCC within plus or minus **[2 inches]** of that stipulated.
4. Keep the elevation of the surfaces of roller-compacted concrete layers upon which subsequent concrete is placed within **[5 inches]** from the design elevation. Additionally, keep the elevation of the top three lifts within **[2 inches]** of that shown on the drawings.
5. Do not vary the upstream and downstream edges of the finished top of structure by more than **[1/2 inch in 10 feet]**. Do not exceed the plan width by more than **[6 inches]** if unformed and **[2 inches]** if formed. Underbuild will not be allowed.
6. Do not vary horizontal alignment of dam contraction joints (vertical joints) by more than **[1 inch in 10 feet]** and **[3 inches in 50 feet]**.

Delete this provision if no contraction joints are included in the design.

3.16 QUALITY CONTROL AND TESTING

A. General:

1. Establish and maintain an effective, on-site, quality control program with the engineer for the roller-compacted concrete. It will be the means of ensuring compliance with contract requirements and of maintaining records of control, including all tests and inspections, their findings, and the remedial actions taken when necessary. All testing and inspections described herein will be the responsibility of the **[contractor] [engineer] [owner's representative]**.
2. Establish and execute the quality control program under the supervision of an RCC Quality Control **[Engineer] [Manager]** who will review and approve all activities concerning the production of materials, planning and scheduling of construction activities for placing RCC, and the running and evaluation of RCC tests. Work closely with the engineer and keep the engineer advised of planned construction procedures, the placing schedule, the testing schedule, and results obtained from tests. Designate an RCC Quality Control **[Engineer]** for each shift. Several personnel may be required in the various areas of activity monitoring, testing, and reporting during the initial placement period. Make all information and test results available to the engineer. Permit the engineer full access to all construction and contractor quality control activities.

3. At a minimum, include the following processes in the RCC Quality Control Program: aggregate stockpiling and handling, aggregate testing, mixing requirements and mix proportions at the RCC mixing plant(s), mix delivery, compaction, **[joints]**, material quality control, **[embedded items], [erection of precast facings]**, and all other tests and inspections required by these specifications. Establish the program as described in the following paragraphs.

B. Aggregate Gradation:

1. Testing: At least once during each shift that RCC is placed and once during each shift that aggregates are delivered, test gradations for each aggregate size and for the combined gradation of all aggregates mixed at the designated proportions. A retest sample is required for any gradation test out of specifications. The location where samples are taken will be selected by the engineer. Make provisions for accurate sampling of aggregates on feed belts to the RCC mixing plant.
2. Action Required: When a test result is outside of the specification limits, take a retest sample. If the retest sample is outside of the specification limits, suspend RCC production until the problem is corrected. The contractor will be responsible for all costs incurred as a result of RCC placement suspension resulting from out-of-specification materials.

C. Aggregate Moisture Determination:

1. Testing: At least once during each shift of RCC placement for each aggregate size used, test the moisture in accordance with ASTM C 566. The obtained sample must be typical of materials entering the mixer. The frequency of testing may be increased or decreased depending on moisture uniformity or variability as a project record is developed.
2. Action Required: When moisture content determinations indicate a change in water entering the mix with the aggregates, contact the placement foreman to see if a corresponding adjustment in water added at the mixer is necessary to obtain adequate compaction and meet consistency requirements at the placement site.

D. Material Finer Than the No. 200 Sieve:

1. Testing: During the first two weeks of aggregate stockpiling, perform tests every other day in accordance with ASTM C 117 to determine the amount of material passing the No. 200 sieve for each aggregate size group. After it has been established that a problem does not exist, and if production remains constant, continued testing will be required once per week.
2. Action: When test results for material finer that the No. 200 sieve are outside of the specification limits, take action to correct the deficiency. Suspend RCC production until the problem is corrected. Materials produced "out of spec" may be blended with materials "in spec" so that the composite as used in RCC meets specification requirements.

E. Aggregate Quantities: Accurately monitor and record the quantity of each aggregate produced, delivered, stockpiled, and used during each shift. Maintain a cumulative record of the amount of each aggregate produced or delivered, used in the permanent work, and wasted. Base quantities on saturated surface-dry (SSD) moisture conditions. Also record the moisture content.

F. Cement and Pozzolan Quantities: Accurately monitor and record the quantity of each material delivered and used during each shift and the quantities of materials stored on-site. Maintain a cumulative record of the amount of each material delivered, used in the permanent work, and wasted.

G. RCC Mixing Plant Control: When the RCC mixing plant is operating, continuously control the amount of all constituent materials including cement, pozzolan, each size of aggregate, water and admixtures. Adjust the mixture proportions to compensate for free moisture in the aggregates as necessary. Prepare a daily report and submit to the engineer before the start of the next shift indicating the type and source of cement used during that day, aggregate size groups used, required mix proportions per cubic yard for each mix design used, the amount of water as free moisture (above SSD) in each size of aggregate, and the aggregate weights per cubic yard of RCC produced during plant operation. Also include in the report the total amount of each material used per shift. Include in the daily report the proportions for each batch, for batch plants, and for each **[10-minute]** interval for a continuous plant.

H. Scales for Weight Batching:

1. Tests and Checking: Check the accuracy of scales with test weights prior to the startup of concreting operations. Retest the scales at least every month of operation thereafter. In addition, retest whenever there are variations in properties of

the RCC that could be the result of batching errors. When weight-batching procedures are used, frequently check the accuracy of each batching device during the startup of operations by noting and recording the required weight and the weight actually batched.

2. Action Required: When either the weighing accuracy or batching accuracy is found not to comply with specification requirements, do not operate the plant until necessary adjustments or repairs have been made.

I. Volumetric Feed Calibrations: Check the accuracy of volumetric feeds by collecting all material delivered to the mixer during a unit of time. Provide suitable methods and equipment for obtaining and handling samples at the RCC mixing plant. Determine the weight of material delivered to the mixer during a time interval between 5 to 15 minutes as determined by the engineer, and calculate the resulting proportions of materials per cubic yard. Determine the accuracy of volumetric feeds at least three times during checkout of the RCC mixing plant prior to production operations and RCC placement. Recalibrate plant at least every **[30 shifts]** or **[15,000 cubic yards]** thereafter, whichever comes first, and whenever there are variations in the properties or control of the RCC that could be the result of volumetric feed errors. Use samples of sufficient size to give accurate determinations. This may require sample weights in excess of 500 pounds per item checked.

J. Testing RCC Mixers:

1. General: Sample and test fresh concrete for compliance with the specifications at the placing location. Provide a method of readily obtaining representative RCC samples from the placement, the plant and gob hopper locations. Approximately **[400 pounds]** of material will be required for each sample.

2. Mixer Performance: If a batch drum mixer is proposed, perform a complete mixer performance test on three different batches of RCC, or runs on each mix, prior to the test section. Additional tests may be made at any time to support a contractor's request for reduction of mixing time. When mixer adjustments are necessary because of failure of a mixer to comply, retest the mixer after adjustment. Mixer performance test are required on a continuous pugmill plant if that plant has not produced RCC of similar proportions in the past. Tests may be required if the RCC shows signs of non-uniformity or inconsistency in test results.

K. Temperature:

1. Testing: Measure and record the RCC temperature on an **[hourly]** basis at the placement location. Perform additional tests when rapid set time or workability loss is reported by the placing foreman or engineer, or during periods of hot or cold weather. Record the temperature of the air and the RCC during the period of cure and cold weather protection when those restrictions are applicable.

2. Action Required: When RCC temperature is outside the specification limits, suspend RCC placement until the problem is corrected. Include temperatures as standard data in the quality control reports.

L. Moisture Content:

1. Calibration of Nuclear Gauge: Calibrate the gauge against oven-dry samples of the mix design used. Verify the calibration to oven dry materials at least once per **[five shifts]**.

2. Tests and Checking: Determine the moisture content of the RCC mix each time a density reading is taken with the nuclear gauge. Determine moisture content at the placement using a nuclear gauge in the backscatter mode immediately after compaction. Drive the probe to the full depth of the lift for each reading. Perform at least three tests in different areas of each layer of RCC placed. Continuously monitor the apparent effectiveness of compaction equipment from a visual standpoint, and notify the mixing plant whenever the mix becomes too dry or too wet.

3. Action Required: When moisture content tests indicate a significant change from what has been established as the optimum mixing and placing moisture, notify the placing foreman who will check the behavior of the mix under conditions at that time. When the placing foreman observes a condition of moisture that begins to consistently allow the vibratory rollers to sink excessively in the mix, cause excessive paste to develop at the surface, or leave an open, unconsolidated appearing surface, make an adjustment to the mix water added at the plant and record the adjustment.

M. **[Mix Consistency (Vebe Time)]**

1 Testing: Determine the Vebe time in accordance with ASTM C1170-91 at the start of production placement, or when there are changes in the workability of the mix that may affect placement, compaction, or other in-place properties. Determine and record the unit weight as part of each consistency test.

2. Action Required: When the Vebe time is outside of the acceptable range, as determined by the engineer, waste the unacceptable RCC and make an appropriate water content adjustment.

If the RCC design mix has a Vebe time this paragraph may be included. Vebe testing equipment is often not readily available. If equipment is available, recommend testing at least once per shift.

N. Cement and Pozzolan: Visually monitor the cement and pozzolan feed to the RCC mix on a continuous basis throughout the operation of the RCC mixing plant. In addition, directly measure and record the cement and pozzolan contents of the RCC, at **[10-minute]** intervals and each time the silos are filled. Use a belt scale to measure the RCC produced between mixing and loading. A load cell placed under the silos or volumetric measurement of the cement and pozzolan used since the last silo filling will be acceptable methods of measuring the cement and pozzolan usage. Report the cement and pozzolan contents to the engineer each time measurements are taken.

O. RCC Specimens for Compression Tests: Forms for cylinders will be rigid reusable type with disposable liners. The **[engineer] [contractor]** will obtain, make, transport, cure, and test all samples. At least one sample per shift but not less than one sample **[per 2000 cubic yards placed]** should be tested. A minimum of **[4]** specimens shall be molded from each sample in accordance with **[ASTM C 1435 or ASTM D 1557]. [The specimens shall be tested at the following ages: one at 7 days, 2 at the design strength age, and 1 reserve]**. Compressive strength testing shall be performed in accordance with ASTM C 39. The density of molded specimens from each sample shall be determined.

It is advisable to determine the density in the field or as soon as possible in the laboratory. Density test results of molded cylinders should be compared to field density test results. When proper RCC mix proportions are used, the field and cylinder density information, along with the cylinder compressive strength, can be analyzed to estimate the compressive strength of the in place RCC (For additional information on strength vs. density relationship, refer to Commentary on Specification Paragraph 3.09 and Figure 3).

P. Density Calibration Block:

1. During the trial placement, construct an RCC block for nuclear gauge calibration. Make the block with a newly fabricated **[30-inch diameter steel mold]**. Weigh the mold before, and after, filling with RCC. Compute the density of the RCC block and use this computed density to calibrate/check the nuclear density gauges.

For small volume RCC projects an RCC block is not used to calibrate the nuclear gauge.

2. Tests and Checking: At least once every **[2 hours]** during placement, determine the density of the RCC after compaction with a calibrated nuclear density gauge. Have at least one gauge at the jobsite at all times during placement on the placement areas at all times. Test each layer of RCC with the nuclear gauge every **[2 hours]** and **[250 cubic yards]** in at least **[3]** separate locations for wet density. Use the direct transmission mode. The running average of **[5]** consecutive in-place density tests shall be not less than 98% of the optimum compaction density value with no individual test less than 96%. Determine the average wet density from the average of two read-

ings taken with the gauge probe at a depth equal to the thickness of the lift. If the two readings vary by more than 2%, repeat the density test. If it is demonstrated early in production that the two readings are consistently within 2%, the two readings can be discontinued. Also measure densities with the gauge probe at **[4 inches and 8 inches]**; however, these readings will not be used to compute the average density. No individual reading of less than **[96%]** of the optimum compaction density will be allowed in any part of any lift. The engineer may perform supplemental density testing with his own gauges.

3. Action Required: When the nuclear gauge indicates a wet density less than required, perform a retest. If the retest indicates less than required compaction, immediately provide additional rolling provided the time limits in Paragraph 3.07.A are met, and determine whether the lower density resulted from insufficient passes of the roller, a change in the mix properties, or segregation at the bottom of the lift. If the mix properties have changed, suspend placement until the problem is corrected. If the problem persists and if the lower density is the result of inadequate rolling, notify the RCC foreman. The engineer may require removal of the inadequately compacted material.

The number of tests per lift will vary depending on the size of the project and the surface area of each lift.

Q. Compaction Equipment:

1. Tests and Checking: Before any compactor is used in RCC construction, check it for correct dimensions, weight, vibratory capacity, and cleanness. At least once per **[12 shifts]** of use, retest the frequency.
2. Action Required: Remove compaction equipment not meeting the physical dimensions and weights required from the project. Correct any roller having improper frequency for RCC compaction. Immediately notify roller operators running at speeds in excess of specification requirements or using improper practices. Correct the problem or, if necessary, replace the operator.

R. Dumping and Spreading:

1. Tests and Checking: Continually observe and monitor dumping and spreading operations to insure that they are done in a manner that minimizes segregation. Routinely check each layer of RCC in its spread condition for evenness and thickness, so that flat, well-compacted layers within the specified thickness tolerance result after compaction. Determine the flatness, thickness, and elevation of each layer.

The flatness, thickness, and elevation of each layer can be determined using a laser or optical level in conjunction with a hand-carried target rod. A laser that emits a rotating or constant light beam in a fixed plane that can be level or inclined should be used.

2. Action Required: When thickness checks on uncompacted RCC indicate an excess or shortage of material, immediately blade off or supplement the layer as needed. Whenever the thickness or elevation exceeds the allowable tolerances, notify the engineer and he will determine what corrective action, if any, is necessary.

S. Preparation for RCC Placement: Where applicable, inspect foundations, construction joints, forms, and embedded items in sufficient time prior to RCC placement to assure that the area is ready to receive concrete. Check forms and facing panels for condition, support, alignment, and dimensions. The placing foreman will be the first level of supervision for all placing operations. The RCC Quality Control **[Engineer], [Supervisor]** will determine if the correct mix is placed in each location, measure and record concrete temperatures, ambient temperatures, weather conditions, time of placement, yardage placed, and method of placement. Do not permit RCC placement to begin until an adequate number of vibratory rollers and spreading equipment of the right size, in working order, and with competent operators are available.

T. Curing and Surface Protection:

1. Moist Curing: At least every **[2 hours]**, 7 days per week, inspect all areas subject to moist curing and lift surface protection. Record the surface moisture condition at that time. If any area has been allowed to dry, it will be considered as improperly cured.
2. Action Required: Clean any area that has been allowed to dry more than 4 hours with a high pressure water jet (3000 psi). Allow the surface to dry to a saturated surface-dry condition and spread bedding mix prior to placing RCC. If any area was allowed to dry less than 4 hours, clean it using a low-pressure water jet (500 psi) and prepare the surface as described above. The engineer may require the contractor to remove improperly cured RCC.
3. Protection: At least every 8 hours around the clock, 7 days per week, inspect all areas subject to cold-weather protection or protection against damage. Record any deficiencies. During removal of cold weather protection, measure concrete and ambient temperature at least every **[2 hours]**. Record and provide temperature measurements to the engineer on a daily basis.

U. **[RCC Coring: After a minimum of 28 days have elapsed following completion of RCC placement in the structure, obtain 6-inch-diameter cores at the locations shown on the drawings. Obtain cores for the full depth of the RCC placement and a minimum of 1 foot into the foundation rock (if placed on a rock foundation). Exercise special care to obtain cores in good condition from all holes. Place each core run in core boxes in the correct sequence. Separate the core runs with wooden blocks marked according to the measured depth at the end of each core run. If core loss occurs, place blocks with a similar diameter and a length equal to the core loss in the core box at the location of the core loss. Label the blocks with the amount of the core loss. If the loss area is not known, show the amount of loss on a wooden block with the letters D.O.R., "Distributed Over Run," marked on it and place the block just ahead of the "End of Run" block. Do not place cores from more than one hole in any box. Using a waterproof marker, label the inside of the lid and all four sides of the outside of the box with the hole number, box number, and depth interval. Fasten the covers securely to the core box and deliver the box to the on-site core storage area as directed by the engineer.]**

Experience has shown that a waiting period of 7 days to 6 months is required to successfully recover RCC core samples in good condition. The length of the waiting period will depend on the properties of the RCC.

PART 4 - MEASUREMENT AND PAYMENT

Measurement and payment for RCC placed in embankment armoring or spillway projects may be on either a lump sum or unit price basis. If variation in quantities is anticipated, a unit price contract provides the greatest flexibility, although a lump sum contract can also be used in these cases, provided that supplemental or contingent payment items are included in the contract for those items that are expected to vary in quantity. Payment for cement and pozzolan at unit prices may be preferred because it allows adjustments to the mix design without price negotiations. The following provides representative measurement and payment provisions for both types of contracts. This information is not intended to supersede or replace a complete measurement and payment specification section but could be incorporated into a "stand-alone" specification section

4.01 MEASUREMENT

A. General: Measurement will be made on the basis of completion of the work in accordance with the contract documents and as stated in the following Article 4.04 titled Item Descriptions. All work completed under this contract will be measured according to United States Standard Measures. No extra or extraordinary measurements of any kind will be allowed in measuring any work; only the actual lengths, areas, solid contents, weights, or numbers will be considered, and the lengths will be measured on centerlines of work, whether straight or curved.

B. Pay Item Descriptions: The item descriptions contained in this section are not to be considered as all encompassing. The prices bid in the proposal constitute complete payment for the work specified in the contract documents, drawings, and specifications.

4.02 PAYMENT

A. General: Payment for all work will be made in accordance with the applicable unit or lump sum prices for each of the items as shown in the proposal.

B. Incidental Costs:

   1. Include in appropriate pay items cost for:

      a. Labor

      b. Equipment

c. Materials
d. Transportation
e. Plant
f. Tools
g. Bonds and insurance
h. Workmen's compensation
i. Licenses
j. Permits
k. Taxes
l. General overhead
m. Profits
n. All other expenses necessary for execution of the work

2. Tests: Incidental to the appropriate pay items, where applicable:
   a. Laboratory and shop tests
   b. Concrete tests
   c. Material and equipment tests

Insert the following Paragraph 4.03 only for unit price contracts or lump sum contracts with supplemental or contingent unit price pay items.

4.03 VARIATIONS IN QUANTITIES.

A. General: The quantity estimates for unit price items are approximate and will be used for comparison of bids. Contractors are specifically advised that the inherent nature of the work included under this contract, including, but not limited to, excavation, foundation cleanup, and foundation preparation is such that variations in actual quantities are likely to occur for these items and other items affected by changes in these items.

Many contracts are written with provisions for unit price adjustments if quantities change more than 15% to 20%. The engineer should assess the potential for quantity changes and determine if such provisions are appropriate.

4.04 ITEM DESCRIPTIONS

A. General: The prices bid in the proposal constitute complete payment for the work of the contract, which work is as specified in the contract documents.

1. Work and services of an administrative nature including all costs associated with partnering activities, which are not referenced in Measurement and Payment statements or in Item Descriptions, are considered incidental to the entire work of the contract, and no separate or additional payment will be paid for such.
2. The proposal item descriptions are not considered a comprehensive description of the entire work involved in the items. All necessary appurtenance equipment, adjoining or attached structures, construction features and materials, and construction operations not mentioned in the item descriptions are considered incidental to the items, and as such, must be included in the applicable bid prices.

Insert one of the following paragraphs as appropriate.

INSERT THE FOLLOWING PARAGRAPH "B" FOR UNIT PRICE CONTRACTS:

B. Pay Item Descriptions: Descriptions of each of the payment items are as follows. Items not specifically mentioned will be considered incidental to the work.

1. Purchase and Stockpile Aggregate: Includes all work required to purchase, transport, and stockpile aggregates at the location designated on the drawings. For the purpose of partial payments, measurement will be based on delivered aggregate weights, not -to-exceed **[90%]** of the proposal quantity. The contractor will be paid for **[90%]** of the aggregates after it is delivered to the site and tested. Final acceptance and payment will be based on the measurement of the actual weight of aggregates meeting the specifications and placed within the lines and grades shown on the drawings based on the saturated surface-dry aggregate batch weight. Payment will not be made for material used to build the aggregate stockpile base.

Modify the previous two pay items as appropriate if only one, or more than two, aggregate size groups are specified.

2. Cement: Includes cement used in roller-compacted concrete. No separate payment will be made for cement used in any other concrete. Measurement will be based on the number of cubic yards of roller-compacted concrete (RCC) placed in the project multiplied by the specified number of pound of cement per cubic yard of RCC (cement content). An adjustment to this quantity will be made if less than the specified cement content is used in the RCC. No adjustment will be made if the cement content exceeds the specified amount without prior approval of **[engineer] [owner]**. Payment will be made at the contract unit price per ton bid for this item.

Because a plus tolerance is allowed for the mixing plant, some engineers suggest that any cement used that falls within the plus tolerance range should be paid for. Without paying for this cement the contractor will always be aiming for the low end which may produce some RCC without adequate cement.

3. Pozzolan: Includes fly ash used in roller-compacted concrete. Measurement will be based on the number of cubic yards of roller-compacted concrete (RCC) placed in the project multiplied by the specified number of pounds of pozzolan per cubic yard of RCC (pozzolan content). An adjustment to this quantity will be made if less than the specified pozzolan content is used in the RCC. No adjustment will be made if the pozzolan content exceeds the specified amount without prior approval of **[engineer] [owner]**. Payment will be made at the contract unit price per ton bid for this item.

4. Mix, Convey, and Place RCC: Includes all work required to mix, convey, place, and cure all roller-compacted concrete placed. Includes all costs of providing mix water and admixtures used in the RCC. Measurement will be made within the lines of the structure as previously described. Payment for overplacement, material placed in the trial placement area, and material that is wasted will not be made. Also includes costs associated with treatment of lift surface and lift edge cold joints as specified, exclusive of bedding mix. Adjust the bid price per cubic yard to cover anticipated placement rates at all locations within the structure. Further, no separate or additional payment will be made for difficult placement areas, such as at the abutments or around conduits. Payment will be made at the contract unit price per cubic yard bid for this item.
5. Trial Placement: Includes all work and materials associated with the RCC trial placement as shown on the drawings and described in the specifications. Measurement will be made on a completed job basis. Payment will be made at the contract lump sum price bid for this item.
6. Bedding Mix: Includes materials, mixing, conveying, and placing bedding mix on the foundation and on all RCC lift surfaces as specified and as shown on the drawings. Payment will be made at the contract square yard price bid for this item. No separate payment will be made for bedding mix used to treat cold joints unless conditions are described for specific cold joints. These may occur weekly or at certain elevations.
7. Contraction Joints: Furnish all equipment, materials, and labor necessary to install vertical contraction joints as detailed on the drawings and at locations approved by the engineer. Payment will be based on the number of square feet of joint(s) constructed or on a linear foot basis. No payment will be made for joints that are required as a result of the contractor's inability to meet schedule requirements or as a result of equipment breakdown or material shortages that could have reasonably been anticipated and avoided by the contractor.

Insert the following payment item if RCC placement spans over two construction seasons and if extended winter protection is required.

8. Winter Protection: Includes all work and materials associated with protecting the exposed surface of the RCC dam during the winter shutdown period. Provide winter protection as required in the specifications, including placing and removing earthfill cover and insulation, cleaning and pressure washing the surface, and covering it with bedding mix. Payment will be made at the contract lump sum price bid for this item. **[40%]** of the value of this pay item will be paid following placement of winter protection. The remaining **[60%]** will be paid when RCC placement resumes the following year.

INSERT THE FOLLOWING PARAGRAPH "B" FOR LUMP SUM PRICE CONTRACTS:

B. Roller-Compacted Concrete: Includes all work associated with producing, delivering, placing and curing RCC including furnishing and handling aggregates, cement, pozzolan, and admixtures; mixing, conveying, placing, and curing RCC; constructing the trial placement; **[installing and removing winter protection]**; and furnishing and placing bedding mix. Payment will be made at the contract lump sum price bid for this item.

END OF SPECIFICATION

Guide for Developing RCC Specifications Commentary

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (continued)

COMMENTARY

INTRODUCTION

The following Commentary is intended to assist the design engineer or specification writer with preparation of specifications for roller-compacted concrete (RCC) embankment armoring and spillway projects. The Commentary is not intended to provide guidelines for design or construction of a project. Where appropriate, references are provided in the Commentary that can be consulted for additional information on the design and construction of armoring and spillway projects.

In some cases, opinions have been expressed in the Commentary. These opinions are based on the experience of the authors and should, in all cases, be verified by the designer to be applicable to the specific project under consideration. Neither the Portland Cement Association nor the authors assume any liability for use or misuse of information contained herein. Further, some of the examples included herein are from new RCC dam projects. However, many of the techniques used for new dams are also applicable to armoring and spillway projects.

During the early part of the design process for an RCC embankment armoring or spillway project, the design engineer must develop the appropriate design criteria for that specific project. When developing project specific design criteria, the design engineer must consider items such as locally available materials, potential contractors and their level of experience for the type of project being considered, local climatic conditions, budget, and owner's expectations. Each element of the design criteria is realized through the project's technical specifications.

Decisions made in the field during construction by either the engineer or the contractor on issues affecting quality control can have a significant impact on the ultimate performance of the project and the bottom line for the contractor. The project specifications must be clear, thorough, concise, and be interpreted and enforced in a consistent and reasonable manner. The areas of the specifications that contain the phrase "subject to the approval of the engineer" or "as directed by the engineer" must be discussed during the pre-bid meeting so that the engineer's expectations are completely understood prior to bids being received. Contractors should be informed as to the importance of specific limitations or restrictions so they can understand their significance to the success of the project and gain a better appreciation for good quality control practices. The overall success of the project for all involved will depend on open communication and flexibility. Unexpected complications are likely to occur, requiring changes to the design, materials, and/or methods of construction to achieve the original design intent. Quick and reasonable approaches must be developed with the project's safety and long-term performance always in the forefront as the ultimate goal.

CONSTRUCTION-PHASE MIX DESIGN AND TESTING (Specification Paragraph 1.05)

Unless the source of materials is selected prior to bidding the project, which is usually not the case, design testing will be required during the construction phase to finalize the RCC mix designs. The testing is typically used to supplement paper mix designs and, in some cases, laboratory testing performed during the design phase of the project. The specifications should clearly state the intended construction-phase mix test program and note any required participation by the contractor, such as supplying representative samples of materials for testing and on-site laboratory and testing facilities.

MATERIALS SELECTION (Specification Paragraph 2.01)

General: Local sources of cement and pozzolans should be investigated to find out what types are available. If low-heat or low-alkali cements are required, there may be limited sources available.

Portland Cement: For most embankment armoring and spillway applications Type I or II cement will be suitable. In cases where type IP is available it should also be considered. In most cases, the additional expense of low or moderate heat cement is not justified. Type V cement is typically specified in areas where the soils have a high sulfate content.

Pozzolan: Class F and C fly ash are the most common pozzolans used for RCC. For very small projects, addition of fly ash is probably not justified because of the costs associated with storing, metering and testing. However, it should be considered for larger projects as it may provide economy, reduce heat generation, improve workability, reduce the potential for aggregate reactivity, and extend the compaction time. Figures 1 and 2 show examples of workability and strength for mixes with and without fly ash.

For example, Figure 1 shows that for a mix with 225 pounds per cubic yard (ppcy) of cement and no fly ash, a water content of 195 ppcy would be required to achieve a workability (Vebe time) of 40 seconds. By contrast, a mix containing 50% fly ash and a total cementitious content of 250 ppcy would require a water content of only 173 ppcy to achieve the same workability. Some pozzolans, particularly Class C, may increase the potential for alkali-aggregate reactivity. The chemistry of the pozzolan should be carefully reviewed prior to final selection of materials for the project.

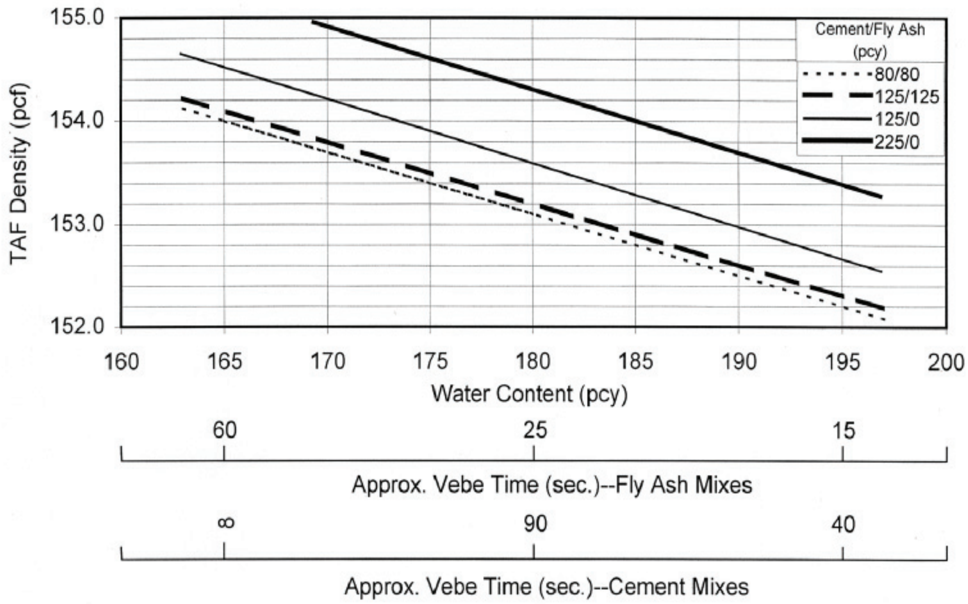

Figure 1. Approximate Workability vs. Water Content (Holderbaum-Unpublished Work)

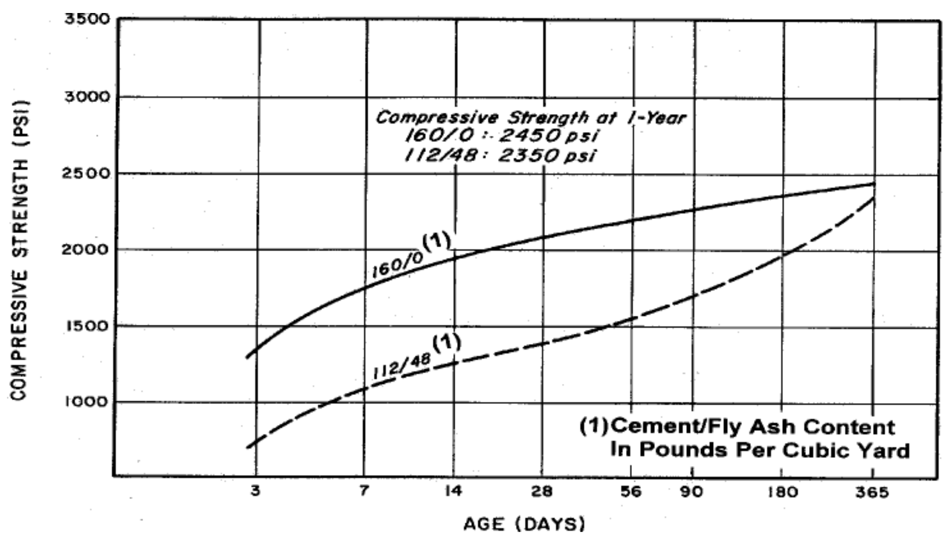

Figure 2. Compressive Strength Comparison - With and Without Fly Ash (Holderbaum, Rodney E. and Kline, Robert A. Published in 1997 ASDSO Annual Proceedings. Pittsburg, PA

Aggregates: Typically during the design phase, local aggregate sources are investigated to identify sources that can produce the quality required for the project. If possible, more than one source should be identified to create competition. As the first choice, on-site aggregate should be investigated to reduce costs. If a suitable on-site aggregate is not available, then commercially produced aggregates should be used for embankment armoring and spillway projects. Except in special circumstances, aggregates meeting the quality requirements contained in ASTM C33 should be used. ASTM #57 and #67 coarse aggregates have both been successfully used to produce RCC and should be acceptable for most armoring and spillway projects. For spillway projects where a smooth surface finish is required, aggregate with a smaller maximum size can be used. Sand may be either a washed or an unwashed product. If a washed product such as conventional concrete sand is used, additional non-plastic fine aggregate is often required to provide cohesion and minimize segregation. Additional fines may also be in the form of additional cement or fly ash. This is usually not a problem since most armoring projects have a fairly high cementitious content to provide the required durability. Table 1 shows combined aggregate gradations that have been used for several armoring and spillway projects.

Some aggregate producers produce an "all-in-one" aggregate such as Department of Transportation (DOT) graded aggregate base material. These materials are produced on a regular basis and at competitive rates; however, DOT specifications generally only specify limits for three to four sieve sizes and a broad gradation band for those sieve sizes. Designing an RCC mix that has an aggregate gradation that falls in the middle of such a large band may not have the properties desired if during construction the aggregate source tends toward either the fine or coarse sides of the gradation band. Plant quality control records should be researched to determine historical variations in the gradation band. If there have been large variations and the plant processing equipment could not be readily modified to consistently produce aggregate within the required gradation band, then that aggregate would likely be unsuitable and a blending of aggregates with more restrictive aggregate gradation bands or a special run should be investigated. Keep in mind, however, if a narrow gradation band is specified, some producers may opt not to provide a material bid. In such cases, multiple stockpiles of various aggregate sizes may be required to achieve the desired combined gradation.

Table 1—Aggregate Gradations for Selected RCC Projects

Sieve Size	Dam Project					
	Siegrist Stilling Basin	**Saltlick Emergency Spillway**	**Ringtown Principal Spillway**	**Long Run Armoring/ Spillway**	**South Prong Dam Overtopping Protection**	**Yellow Creek Dam No. 17 Overtopping Protection**
2 Inch	100	100	100	100	90–100	100
1.5 Inch	100	100	100	100	–	85-100
1 Inch	99	100	100	100	–	70-100
3/4 Inch	91	98	98	95	55–90	60-80
1/2 Inch	–	74	65	80	–	50-70
3/8 Inch	60	60	52	70	40–60	40-60
#4	49	52	41	53	30–47	32-50
#8	38	42	33	34	–	26-42
#10	–	–	–	–	20–40	--
#16	23	32	26	23	–	20-35
#30	14	24	16	15	–	14-28
#40	–	–	–	–	10–30	--
#50	10	16	9	12	–	8-22
#100	6	6	4	8	–	4-15
#200	5	2	2	6	4–20	0-7

Water: In general, water should meet the same requirements as for production of conventional concrete. If an on-site source of water is used it should be tested to determine its impact on strength and set time of the concrete. At Big Haynes Dam in Georgia, on-site well water increased the initial set time by 15% over water from other sources. If an on-site source of water is available, it should be tested and approved or rejected prior to bid.

Bedding Mix: Aggregate with a significantly higher percentage of fines passing the #200 sieve (up to 15 percent) has been used successfully in many bedding mix designs. With a higher fines content, however, the plasticity index (PI) of the fines becomes more important to the workability of the mix. A higher aggregate fines content can make for a highly workable bedding mix with reduced segregation potential provided the PI is low or, preferably, the material does not have a measurable PI. The decision to allow a higher percentage of aggregate fines should be made by the materials engineer with consideration of the actual materials proposed for the project.

Chemical Admixtures: Sufficient testing and evaluation have been completed to show that admixtures can be effective in RCC. Water-reducing, set-retarding, and air-entraining admixtures have all been effectively used; however, they should be used only when absolutely necessary and after full evaluation in the laboratory. High dosage rates are usually required for admixtures to be effective. In addition, the RCC should have a measurable Vebe time. In ACI Committee Report 207.5R it is reported that admixtures have been used successfully in RCC mixes with Vebe times in the range of 10 to 30 seconds and that water-reducing and set-retarding admixtures were effectively used at Elk Creek Dam. The effectiveness of air entrainment can be tested with an air meter identical to that used to test conventional concrete (ASTM C23 1). The effect of retarding admixtures should be evaluated by set time testing of the mortar fraction of the RCC (ASTM C403).

MIX DESIGN(S)
(Specification Paragraph 2.02)

Design Responsibility: Although it is probably best for the design engineer to design and proportion RCC mix(es) for the project, it is also acceptable for the designer to provide a performance specification and require the contractor to design the RCC mix(es). In these cases, the designer needs to completely identify all required in-place concrete properties and define the battery of tests that are required to demonstrate that the contractor's proposed mix(es) meet the specification requirements. All but the most sophisticated contractors will have to hire a consultant and/or testing laboratory to perform this work. At a minimum, if the contractor has the responsibility for mix design, he should be given minimum requirements such as design strength, MSA, minimum cement content, etc.

Technical Approach: The technical approach selected for RCC mix design will depend on the designer's preference and prior experience. There is currently a lack of agreement within the industry on design approach. As a result, several techniques for RCC mix design have evolved and any of these techniques can provide satisfactory results if they are correctly applied. A general description of various design approaches can be found in ACI Committee Report 207.5R, "Roller-Compacted Mass Concrete." Specific details of each approach, however, are not provided in this document.

Design Guidelines and References: Numerous reference documents that provide information on RCC mix design are available to the design engineer. Several documents that provide specific RCC mix design procedures are listed below:

(1) U.S. Army Corps of Engineers, EM 1110-2-2006, *Roller-Compacted Concrete*, February, 1992.

(2) U.S. Department of the Interior, Bureau of Reclamation, ACER Technical Memorandum No. 8, "Guidelines for Designing and Constructing Roller-Compacted Concrete Dams," June 1987.

(3) Tatro, S. B., and Hinds, J. K. "Roller-Compacted Concrete Mix Design," Symposium Volume of the American Society of Civil Engineers, February 1992.

(4) Dolen, T. P., "Mixture Proportioning – The Concrete Approach," Proceedings of the International RCC Dams Seminar & Study Tour, September 1998.

(5) Choi, K., "RCC Mix Design – Soils Approach," Proceedings of the International RCC Dams Seminar & Study Tour, September 1998.

(6) Schrader, E. K., "Roller-Compacted Concrete for Dams – State-of-the-Art," Invited Paper for International Conference on Advances in Concrete Technology, Athens, Greece, May 1992.

(7) McDonald, J. E., and Curtis, N. F. "Applications of Roller-Compacted Concrete in Rehabilitation and Replacement of Hydraulic Structures," U.S. Army Corps of Engineers, Technical Report REMR-CS-53, April 1997.

(8) Holderbaum, R. E., and Kline, R. A. "Roller-Compacted Concrete Mix Design and Testing," Association of State Dam Safety Officials Annual Conference, Pittsburgh, PA, 1997.

(9) American Concrete Institute, Committee 207, ACI 2.07.5, *Roller-Compacted Mass Concrete*

(10) McLean, F.G. and Hansen, K.D., "Roller-Compacted Concrete for Embankment Overtopping Protection," Geotechnical Practice, Dam Rehabilitation, Raleigh, NC, ASCE, New York, April 1993

Criteria: The criteria for design of RCC mixes should be:

(1) Provide adequate strength to meet structural design loads with normal factors of safety.

(2) Minimize internal heat rise from hydration and subsequently developed stress or crack potential.

(3) Provide a constructible mix.

(4) Provide a durable wearing surface.

(5) Provide economy.

Testing and Procedures: Laboratory tests are necessary to develop mix properties for the design of the structure and set density targets for use in the field. Although roller-compacted concrete has been in use for over 25 years, very few standards currently exist that have been specifically developed for testing RCC. Test methods, procedures, and equipment to some extent are dependent on the method selected for the RCC mix design and the desired properties of the RCC mix. General test procedures are described in the references included in the paragraph titled "Design Guidelines and References." ASTM standards that are currently adopted specifically for RCC include:

ASTM C1170 – *Determining Consistency and Density of Roller-Compacted Concrete Using a Vibrating Table*

ASTM C1176 – *Making Roller-Compacted Concrete in Cylinder Molds Using a Vibrating Table*

ASTM C1435 –*Standard Practice for Molding Roller-Compacted Concrete in Cylinder Molds Using a Vibrating Hammer*

In addition, ASTM standards developed for conventional concrete are often applicable for RCC or can be adapted to RCC with suitable modifications. An experienced engineer or lab technician should be consulted if there is any question regarding the applicability of a particular test or procedure.

Molding RCC Cylinders: There are two primary approaches for preparing RCC cylinders in the field for the drier mixes (Vebe times greater than about 30 seconds). They are the vibrating hammer and the pneumatic pole tamper. The vibrating hammer method has been in use for a number of years and is approved as an ASTM test procedure (ASTM C1435). This method works well on moderately dry mixes but may not produce enough compactive effort for the very dry mixes. For the drier mixes the pneumatic pole tamper has been used successfully to compact RCC in cylinder molds. Special cylinder collars are required to keep the tamping head from striking the edges of the mold due to the large amplitude of the tamping head.

For wetter mixes with Vebe times of less than about 30 seconds, either the vibrating hammer or Vebe apparatus (ASTM C1176) can be successfully used to mold cylinders. RCC may not be fully consolidated by the Vebe apparatus for Vebe times greater than about 30 seconds.

Soil compaction rammers have also been used to mold RCC cylinders. A concern with this method is the potential for aggregate breakdown during compaction, particularly with drier mixes. In one study conducted, a test in which the gradation of the RCC aggregate was determined before and after compaction by this method found that significant aggregate fracturing can occur, especially with lower quality aggregate (Holderbaum, Rodney E. and Kline, Robert A. Published in 1997 ASDSO Annual Proceedings. Pittsburg, PA). If aggregate fracturing is significant, the compressive strength determined in the laboratory may not be representative of what can be achieved during construction.

Mix Adjustment During Construction: Mix adjustments during construction are often necessary and can be easily accommodated. The need for cement and/or pozzolan adjustments in most cases will be determined from test results that show both the anticipated in-place properties and variability of the RCC. Adjustment to aggregate gradations or proportions can be necessitated by observing segregation during handling or by a requirement for a better surface finish on spillway slabs. Addition of admixtures may be desired as a result of a delay of placement in warmer climatic conditions. For example, a set retarder could be used to extend the working time during warm weather placing conditions. In all cases, except for water content adjustments, mix adjustments should be made by the design engineer, and only when sufficient test data are available to support the change. Water content adjustments can be assigned to the contractor, provided that an upper limit is provided by the specifications.

EQUIPMENT SELECTION (Specification Paragraph 2.03)

Plant Type

General Background: Many kinds of mixing plants have been used successfully for production of RCC. Continuous-mix and batch-type mixers have both been employed for a wide range of RCC mixes. For small volume projects, volumetric proportioning pugmill mixers have been used the most because of their availability and simple setup. Although batch-type drum mixers are capable of mixing RCC, bulking in the mixer reportedly reduces mixer capacity as much as 15%. Continuous-mix plants can have difficulty in monitoring cement and pozzolan contents, although when properly calibrated have been found to provide adequate accuracy. Continuous-mix plants typically have greater production capacity compared to a comparable batch-type drum mixer; however, they also have greater power requirements. Although weight controls are not normally necessary with the type of mixes to be used, the contractor may submit for approval a mixing plant that uses weight controls.

Specification Considerations: Pugmill mixing plants are generally accepted as being more efficient for mixing RCC and should be given first consideration if the designer is specifying the plant type. Drum mixers may be permitted by the specifications, but precautions concerning their use and potential additional costs associated with bulking and segregation should be addressed in the specifications. Transit truck mixers have been found to cause significant segregation for mixes with aggregate larger than one inch. For very low volume projects, transit truck mixers may be the most economical choice. Care must be taken to avoid segregation and wide swings in moisture. To adequately discharge the RCC, the front of the truck must be higher than the back of the truck.

Mixing Plant Capacity: Mixing plant capacity is a function of the required RCC placement quantity; hourly, daily, or seasonal time limitations; lift variability; and other concurrent activities. It is not uncommon for mixing plant capacity to be 30% higher than the designed sustainable production capacity and 100% higher than the project average placement rate. For large volume projects with extremely critical schedules, the designer may want to specify the minimum number and capacity of concrete plants. Otherwise, selection can be left to the contractor. For small volume projects, a plant capacity of 100 cubic yards per hour is usually sufficient to meet the contractor's planned placement rate.

Mixing Plant Operation: Continuous mix pugmills are designed to operate most efficiently on a continuous basis with few stops and starts. For most overtopping protection and spillway projects, the placement production rates will be low, with only a few hauling vehicles required to maintain an adequate supply of RCC from the mixing plant to the lift surface. This typically results in the continuous plants stopping and starting on a frequent basis. One way to minimize the number of interruptions is to have a large capacity gob hopper that serves as a temporary storage device so the plant can continue to operate even though a hauling vehicle is not available. Requiring a large gob hopper may be an unnecessary expense for smaller volume projects.

The issue in question is what is the quality of the RCC during the first seconds of plant operation after the plant has been stopped. If the pugmill has previously discharged the entire contents of the mixing chamber, the RCC produced when the plant restarts, except for a nominal amount, will be properly proportioned and uniformly mixed. Many RCC specifications require that the first 1-2 cubic yards of material produced after a plant shutdown be wasted. In most instances this is unnecessary waste. The specifications should allow for the engineer to reject any RCC not mixed in the proper proportions or consistency, but stipulating an arbitrary amount of material to be wasted is overly restrictive. The engineer should monitor the plant operations during startup and then decide if any material should be wasted. It may be prudent that at the start of each day, or if the mixing plant has been inoperable for over 30 minutes, that the first 10–20 seconds of material produced be wasted. Prolonged plant shutdowns can sometimes cause initial material feed problems. During the test section construction, the engineer should observe the operations of the plant and the consistency of the mix during all phases of the plant's operation.

Mixing Time: Many of the earlier RCC specifications were written requiring continuous pugmills to have minimum mixing times of 20–30 seconds and have the ability to increase the mixing time. The majority of the continuous pugmills in the United States do not have the ability to modify the amount of time the material is in the mixing chamber. Specifications have suggested inclining the mixing chamber or reversing the paddles as ways of increasing mixing time. These options have been found to have negligible effect. Historically, the performance of the continuous pugmills in producing a uniform RCC mix has been excellent and these types of pugmills have been used on the majority of RCC projects.

If the contractor proposes to use a pugmill that has mixed RCC of similar proportions and has an operator experienced with the plant and RCC, his plant should be acceptable. As always, the selection of the equipment for RCC mixing is the contractor's responsibility, and if during production his plant proves unacceptable in producing a uniform RCC mix, he must either make corrections to his plant or replace it with a different one.

Delivery Equipment: RCC has been delivered with end-dump trucks, bottom-dump off-road haulers, front-end loaders, and conveyors. For smaller projects, except where access is difficult, conveyor delivery may not be practical. Although not the best choice from a quality standpoint, armoring projects are often well suited for truck delivery due to their size and general layout. If the RCC mix is well proportioned, has a small maximum size aggregate, a high sand content, and a moderate to high water content, dumping from an end-dump truck can usually be tolerated. If trucks are used to deliver RCC, restrictions should be incorporated in the specifications to minimize segregation such as not allowing discharging RCC directly against any formwork.

Spreading Equipment: Spreading equipment should be limited to a D-4 or comparable size dozer for small projects and a D-6 for large projects. ABG pavers have also been used. A front-end loader is often required for placing material in confined areas.

SCHEDULE CONSIDERATIONS (Specification Paragraph 3.01)

Thermal Stress Considerations: In general, a thermal stress analysis is probably not required for most armoring and spillway projects if cracking can be tolerated. The need to perform a thermal stress analysis will depend on the size and complexity of the project. Several general guidelines should be considered, however, if specifying the placement time and schedule:

(1) Thermal stresses and cracking can be minimized by placing during cool weather in the spring of the year. Placement during the fall season may subject "young" RCC to thermal shock if proper insulating precautions are not taken.

(2) If possible, RCC should be placed when the daily average temperature is below the mean annual temperature of the site.

(3) Advance stockpiling of aggregates during cold weather will probably not be beneficial unless the project and the stockpiles are large.

(4) Night placement during hot weather in combination with daytime shutdown and an effective curing system can significantly reduce peak RCC temperatures.

(5) A highly effective moist cure during warm weather is essential.

Special Restrictions: Meeting the specified placement dates is necessary to obtain the desired in-place properties of the RCC and to minimize the potential for cracking. If the contractor fails to meet the required schedule, the engineer should perform a re-analysis of the placement schedule and advise the contractor of any special requirements or restrictions that must be taken to obtain similar in-place material properties. The analysis will require a minimum of 7 days to complete. During that time, the contractor should not be permitted to place RCC without prior approval from the engineer. Special restrictions or requirements that might be necessitated include, but are not limited to, reduced or accelerated placement rates, installation of surface insulation following placement each day or at completion of all RCC, pre- or post-cooling of materials, and placing during specified hours each day.

Lift Joint Quality: While often an important issue for most RCC dams, the concern for lift joint quality is greatly reduced for most embankment armoring projects. That is not to say that joint quality can be totally ignored. However, very little cohesion is probably needed to satisfy most designs. Therefore, schedule requirements do not necessarily need to be driven by lift joint quality requirements, and specifications should be prepared accordingly. For spillways with high velocities, however, the design may require development of tensile strength across lift joints to prevent delamination of lift layers during high flows. In these cases, lift joint quality requirements may necessitate placement quickly and during cool weather to achieve the required bond strength. If this cannot be accommodated, bedding mix may be needed for joint treatment.

A Lift Joint Quality Index score card has been developed which assigns both positive and negative points to factors such as surface segregation, lift maturity, type of delivery systems used, curing, etc.(1) On small projects, such a score card is cumbersome to use in the field; however, these factors provide guidelines that should be in the minds of everyone working on the lift surface. Because many of the factors used to evaluate the condition of a lift surface are somewhat subjective, it is important to develop a clear understanding of lift joint treatment requirements with the prospective contractors during the bid period. Small isolated areas of contamination, such as an oil leak or dirt from a dozer track, do not generally require special attention but should serve as a reminder to the contractor to remedy the situation before it affects production.

Cost Considerations: The lowest project cost will be achieved when the least schedule restrictions are placed on the contractor. Unless the owner requires completion by a certain time, or technical reasons require placement during a particular time of the year or at a particular rate, the work schedule should be left to the contractor.

FOUNDATION PREPARATION (Specification Paragraph 3.02)

Placement on Rock Foundations: If placement on a rock foundation is required by the design, cleanup and preparation of the rock surface should be comparable to that performed for conventional concrete placement on rock surfaces. All loose rock, soil, debris, mud, ice, and snow must be removed, and the rock surface must be absolutely free of any flowing water prior to placing RCC. If a high degree of shearing resistance is to be provided by the foundation, bedding mix should be placed on the rock surface immediately prior to placing RCC.

Placement on Earth Foundations: The compactability of the first two or three lifts of RCC on an earth foundation depends in part on the density of the earth subgrade. It is essential that all loose or wet material be removed and replaced with suitable earth backfill. The entire subgrade should be moisture conditioned and compacted with compactive effort equal to or greater than that used for the RCC. The designer should include a separate specification in the bid documents that describes requirements for subgrade treatment, fill placement, and compaction.

Foundation Dewatering: Achieving a suitably dewatered foundation is a common problem for placement areas located below local groundwater. Most RCC mixes are adversely impacted by additional water; therefore, dewatering the placement area to dry or slightly damp conditions is essential. Any of the common methods for dewatering deep foundations can be

(1) Schrader, E.K., "Shear Strength and Lift Joint Quality of RCC," Hydropower & Dams, Vol.VI, Issue One, 1999.

used for RCC embankment armoring and spillway projects. However, the specifications should clearly state whether dewatering facilities will be permitted within the placement area and, if so, the maximum number and minimum spacing of dewatering points. Closely spaced obstacles within the placement area will seriously affect the placement speed and quality of the RCC. Earth materials that are saturated are a common problem encountered in embankment armoring projects. The subsurface exploration program should identify such potential problem areas. Project specifications and bid documents should advise the contractor of potential problems and allow time in the schedule for drying of materials.

Use and Design of Bedding Mix: Bedding mix is often used between rock foundations and the first RCC lift and between RCC layers to increase the lift joint shear strength and decrease joint permeability. For most embankment armoring and spillway projects, the need for bedding mix is minimal. If required by the design, bedding mix that can be easily handled and placed should be specified. Two types of bedding mix have been used. The first type of bedding mix, often referred to as bedding mortar, contains only fine aggregate and can be spread to a thickness of 1/2 inch to 1 inch. It is easier to handle and spread than bedding mix containing coarse aggregate. The second type usually contains aggregate with a maximum size of 3/4 inch or 1 inch and is placed at a thickness of one to one-and-a-half times the maximum aggregate size. This type of bedding requires additional cost to produce and is more difficult to transport and place. If the slump is too high, the coarse aggregate will segregate from the mix if not handled properly. Except in cold weather, bedding mix should contain a water reducing/retarding admixture to prevent rapid set and loss of workability.

For overtopping protection and spillway projects, bedding mortar is typically specified for the top 2 to 3 lifts in the stilling basin or run-out apron, and at the crest of the structure. These locations have very little confining weight in which to mobilize the shear friction, so cohesion between lifts becomes important.

PLANT CALIBRATION AND TESTING (Specification Paragraph 3.03)

Procedures for concrete plant calibration vary depending on the type and manufacturer of the plant. This Commentary is not intended to provide a definitive guide to plant calibration; however, several pertinent observations are offered for consideration.

Although plant types vary considerably, one of the most common plants for mixing RCC is the continuous mix pugmill plant. For this type of plant, the final test of calibration should include direct measurement of weights of each individual material metered through the plant over a set time period. With this information, the actual feed rates can be computed and then compared with the theoretical plant setting to determine if material feed rates are within specified tolerances. Plant manufacturers should be consulted if there is any question regarding acceptable calibration procedures.

During construction, the plant should be re-calibrated any time a plant setting that controls cement, pozzolan, or aggregate feeds is modified. Even minor changes to plant settings have been discovered to result in significant changes to material feed rates resulting in RCC that does not meet specifications.

AGGREGATE PRODUCTION, DELIVERY, AND HANDLING (Specification Paragraph 3.04)

Aggregate Stockpiling: When a narrow gradation band is specified, there are several locations where the material may fall out of specification after it leaves the producer. Proper construction of the on-site stockpile is essential to prevent segregation. Both the engineer and the contractor must monitor the delivery of the aggregate and instruct equipment operators on proper stockpiling procedures to minimize segregation. Before RCC production, the loader operator feeding the mixing plant must be instructed on proper loading methods from the face of the stockpile to prevent delivery of "out of specification" aggregates to the mixing plant. Pre-placement training of the equipment operators can help alleviate most of the problems associated with aggregate segregation.

One acceptable method of stockpiling is delivery by truck onto the top of the stockpile, dumping the loads in adjacent piles, spreading the piles with a bulldozer, and repeating the process in spread layers to raise the pile. Care must be used to avoid substantial spilling of material over the edge of the piles, causing a segregated outside shell of unsuitable material. Care must also be taken not to excessively track portions of the stockpile with the bulldozer. Excessively tracking the stockpile can break down the aggregate and significantly alter the gradation of the stockpiled aggregate.

In general, temperature monitoring of stockpile temperatures is not necessary for embankment armoring and spillway projects. For projects that do require monitoring, specifications for the thermocouples and installation should be provided in this section or in a separate instrumentation section. The number of thermocouples required, the frequency of reading, and the frequency for submission of readings to the engineer should be specified as appropriate. If temperature is a significant concern, the design engineer should consider inclusion of a detailed delivery schedule.

TRIAL PLACEMENT (Specification Paragraph 3.05)

The test section is intended as a practice, training, and orientation area; to help evaluate the practical effectiveness of various construction methods and pieces of equipment; to practice quality control requirements; to make final mix adjustments; and to determine the optimum compaction density value. The trial placement will also serve as a practice area for inspection.

General: A trial placement that is outside of the permanent work or incorporated into a non-critical structure is usually required to visually verify mix properties, confirm achievable in-place density, and provide a practice area for the contractor.

Specification Details: The specifications should describe the requirements and anticipated outcomes of the trial placement in as much detail as possible. It should be clearly stated that if the goals are not achieved, the scope of the trial placement will be increased. The measurement and payment section of the bid documents should address payment for the Trial Placement, including increased scope caused by either the contractor or engineer.

CONVEYING AND TRANSPORTING (Specification Paragraph 3.07)

System Coordination: Delivery equipment must be compatible with the plant capacity and the capacity of spreading and compaction equipment on the lift surface. The specification need not provide detail on this issue, but it should require contractor submittals to include rates for all activities.

Haul Vehicles: As previously stated, RCC has been hauled in end-dump trucks, off-road bottom-dump haulers, and front-end loaders. All three types of vehicles have been used successfully with proper precautions and placing procedures. Although end-dump trucks are probably the most common haul vehicles used for small projects, their use will result in some segregation with most RCC mixes. However, many of these projects can tolerate a small amount of segregation. Further, additional measures can be employed on the lift surface to remove and/or reblend segregated material.

Conveyor Systems: Belt conveyors typically are not required to successfully construct embankment armoring or spillway projects. If the project is located in a very wet environment or if a high degree of lift quality is required for technical reasons, the design engineer may specify a conveyor delivery system. Otherwise, the choice of delivery should be left to the contractor. In some cases a partial conveyor system might be appropriate; for example, conveyor delivery from the mixing plant to a transfer point on the lift surface.

If conveyors are used, careful attention should be given to matching the capacity of plant and spreading equipment on the lift surface. This information should be requested as part of the submittal process.

Portable conveyors that are used for transport of conventional concrete, aggregate, and coal have all been used successfully for transport of RCC. Conveyor transfer points, however, can often be a source of problems and can result in significant down time.

PLACING AND SPREADING (Specification Paragraph 3.08)

Selection of Temperature Restrictions: The specifications should set a lower and upper limit on the allowable temperature of fresh RCC delivered to the lift surface. The lower limit is to prevent frozen RCC from being placed, while the upper limit is to minimize the potential for development of high thermal stresses. Thermal stresses may produce strains that exceed the capacity of the RCC, resulting in uncontrolled cracking. For overtopping protection and spillways with infrequent flows, cracking is generally not a problem, but if the structure will experience frequent flows, minimizing uncontrolled cracking is a consideration.

Most RCC embankment overtopping protection and emergency spillway projects do not include transverse contraction joints. The maximum allowable RCC temperature is a function of the average ambient temperature in the geographical area of the project, daily and seasonal temperature fluctuations, and the expected rise in temperature of the RCC mix as the cement hydrates. The difference between the temperature of the RCC mass and the outside ambient temperature can create thermal stresses. To minimize the potential for a large differential between the two temperatures, an RCC placement schedule "window" is often defined in the specifications. Some designers will allow the RCC to be 15 °F greater than the annual average temperature at the site if RCC placement is during the day and possibly more if RCC is placed at night. Several projects have used a daily weighted-average maximum temperature that provides some relief to the contractor. While record keeping can be tedious, this concept allows the contractor to increase total placement hours, because placing during the cooler night-time temperatures usually offsets higher RCC temperatures that result during warmer daytime conditions.

During the development of the preliminary design of the project, the RCC mix design, thermal analysis (if performed), and project schedule will all play a part in determining the temperature restrictions and time of year when the RCC must be placed. The project schedule must allow enough time for all of the required front-end work to be completed in preparation for the RCC placement, with some contingency time built into the schedule to accommodate items such as inclement weather and unforeseen subsurface conditions. Without flexibility in the mix design or schedule, missing any specified placement windows may result in the owner and/or the contractor incurring expenses associated with cooling the various mix components and/or the RCC mix. Adequate planning during the design process and developing contingency plans for alternative RCC placement schedules will help prevent excessive delays and additional costs during construction.

Placing During Precipitation: Experience has shown that placing RCC during a temporary light mist can usually be accomplished with care, but if hauling vehicles rather than conveyors are used for delivery, it is relatively easy to contaminate or damage the surface and subsequently have to clean it. If rain alters the mixture proportions beyond acceptable limits, the RCC will need to be removed. The contractor should have provisions to cover the lift during periods of heavy rains.

Selection of Lift Thickness: For most projects a lift thickness of 12 inches should be specified by the design engineer. Although thicker lifts have been used in some instances, complications arising from use of thicker lifts are not usually justified for most armoring and spillway projects. Thicker lifts require additional compaction trials and testing to confirm that the desired in-place density can be achieved. Placement of thicker lifts may also complicate grade control and nuclear density testing. By contrast, 12-inch lifts have been used for many projects and can be adequately compacted with common compaction equipment. The specifications can require RCC to be placed in 6-inch lifts against formwork to achieve better compaction for the full depth of the lift or in other areas where a large vibratory roller cannot operate properly.

Equipment Selection: Ultimately, the contractor has the responsibility for selecting equipment that is suitable for placing and spreading RCC. However, the engineer is often required to review contractor equipment submittals. As a general guide for spreading equipment, a D-3 can be expected to spread a 12-inch lift at a maximum rate of about 100 cubic yards per hour. A

D-5 has a spreading capacity of nearly 200 cubic yards per hour. The capacity of the spreading equipment, however, is highly dependent on the method of RCC placement, the care taken in grade control, and operator ability.

COMPACTION
(Specification Paragraph 3.09)

Determination of Required Density: The density of the RCC has a direct role in the strength of the RCC. Two factors that can produce changes in the density during construction, assuming compaction effort is unchanged, are the moisture content and changes in the aggregate gradation, including segregation. Moisture content can be easily adjusted at the mix plant, but segregation and/or changes in the gradation of the aggregate may be more difficult to manage because of the number of different handlers of the material.

Numerous projects were studied by observing the maximum density achieved versus the compressive strengths of RCC samples (Schrader-Unpublished Work) (See Figure 3). The data indicates that for compacted densities between 97% and 100% of theoretical air-free density, the compressive strength of the RCC showed little variation. However, as the air-free density drops below 96%, strength loss occurs. The Bureau of Reclamation requires 99% of the average maximum density (AMD) achieved during lab compaction trials. They consider this requirement, along with a highly workable mix, essential to achieve full compaction of the RCC lift. There are some concerns that settling for a minimum density of 97% of AMD will not ensure adequate density at the bottom of the lift. The concern of the Bureau may be justified if a large aggregate is used in combination with a mix with a low degree of workability. (Note: The reader should be aware that 99% of the AMD is not equivalent to 99% of air-free density because there are some voids—usually 1% to 2 %—in the RCC mass after compacting the RCC to reach the AMD).

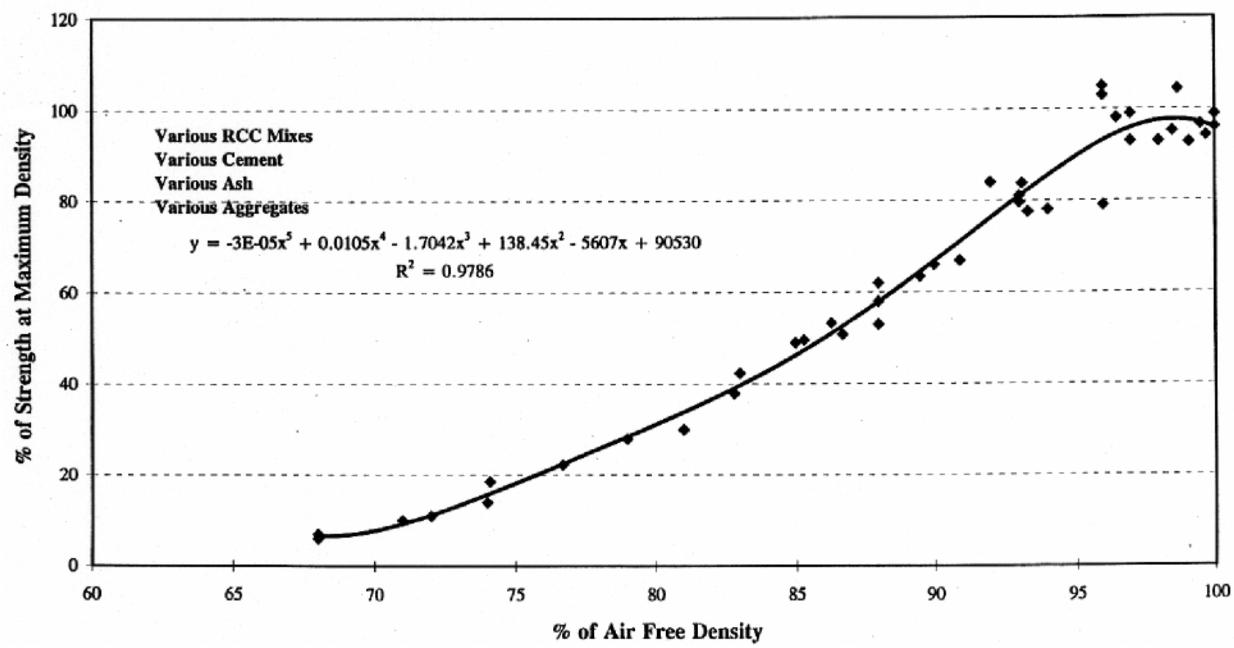

Figure 3. Strength vs. Density for Various RCC Mixes (Schrader-Unpublished Work)

At least four different methods have been used to determine the control density used during construction. Often engineers will use more than one method to confirm that adequate compaction is being achieved. The appropriate method will depend on the mix design and other factors. Each method is described below.

Calculation of theoretical air-free density. One method for establishing the required minimum density is to specify a percentage of the theoretical air-free (TAF) density for the RCC mix. Typically, the specific gravity is known or determined for each component in the RCC mix, which allows computation of the TAF density with good precision. Typically RCC will have 1% to 2 % of entrapped air, so one should not expect to achieve 99% of TAF on a regular basis during production. The appropriate density for field control should be 96% of TAF.

Soil compaction techniques. Soil compaction control tests can be used for RCC mixes with small maximum size aggregate and higher cementitious contents. Typically, a compaction curve is developed using ASTM D1557. For well-proportioned mixes, the maximum wet density achieved with the ASTM D1557 compaction equipment and compaction effort is approximately 98% of the theoretical air-free density. For most RCC mixes, an appropriate density for field control would be 97% to 98% of the maximum ASTM D1557 wet density.

Proof rolling. Proof rolling of RCC can be used to determine the maximum, practically achievable density, referred to as the Optimum Compaction Density (OCD) or Average Maximum Density (AMD), for actual construction conditions. The maximum (proof) density is determined by measuring the density after each one or two passes of the roller, usually with rollers having a minimum weight of 10 tons. For RCC, the proof rolling has to be performed as soon as practically possible after spreading, especially during warm weather, to prevent loss of compactability resulting from loss of moisture and initial stages of hydration. For most RCC mixes, an appropriate density for field control would be 97% to 98% of the maximum wet density achieved by proof rolling.

Most designs are based on RCC properties obtained in the laboratory under a controlled environment. Densities obtained in the laboratory may be higher than those obtained during proof rolling. If target density is to be determined by proof rolling, the maximum density achieved should be checked against that obtained in the lab. If there is a significant difference, the reasons for the difference and its effects on the design criteria should be identified.

Lab density. This is the design approach favored by the Bureau of Reclamation and the Corps of Engineers. A principal goal of this approach is to develop a workable mix. The wet density of RCC is measured in the lab either by consolidating the RCC on a vibrating table (Vebe apparatus) or by compacting the RCC in an air pot with a tamper. The density achieved in the lab can be used to control field compaction. Lab densities, however, can vary depending upon the consistency of the RCC mix and the method of density measurement. These variations need to be carefully studied to determine the appropriate compaction requirement. Few RCC overtopping projects have used an RCC mixture having low Vebe times (less than 15 seconds) due to excessive movement of the mix if one edge is not formed or restrained.

Effects of Overcompaction: Some compaction trials have shown that the in-situ density of RCC may decline with an excessive number of roller passes. With drier RCC mixes, loosening of material may be observed at the surface of the lift. After the optimum number of roller passes is determined, either in trial placement or during project construction, passes beyond the number necessary to achieve acceptable density should be avoided.

Selection of Compaction Time: The compaction time is defined as the elapsed time from when water is first introduced into the mixer to when the desired density requirement from compaction is satisfied. Studies have shown that after the RCC mix has achieved its initial set and is then compacted, a strength loss will occur. Many specifications have been written with a maximum compaction time of 45 to 60 minutes, which is adequate for most mixes using some fly ash and when placement occurs in cool weather. For mixes with cement only, or when RCC is placed in warm weather, specifications may limit compaction time to as little as 30 minutes. Under some placing conditions, this is a difficult requirement to achieve consistently, especially when starting a lift, delivery is with haul vehicles or in confined areas.

Most RCC embankment overtopping protection and emergency spillway projects are small in scope, and, therefore, "time of compaction tests" are seldom performed. However, such a test might be appropriate when the mixing plant is not located on-site. The contractor might be allowed to pursue this testing if his proposed means and methods require more time than allowed in the specifications.

Two tests have been performed to guide the designer's selection of the appropriate compaction time. The tests must be performed with the exact mixes and materials that are to be used for the project. Additionally, the materials must be at the same, or higher, temperature as the RCC to be placed during construction. If, during construction, RCC is placed at higher temperatures, the testing should be repeated. In the first test method, RCC cylinders are molded at various time intervals after compaction. Concurrent testing should also be performed to determine the effect of delayed compaction on achievable density and workability. The allowable compaction time is selected at the point where compressive strength and workability of the RCC exhibit unacceptable decline. In the second method, set-time testing is performed on the mortar fraction of the RCC. The allowable compaction time should be selected so that it is less than the initial set time of the mortar or less than the time when workability and/or compressive strength exhibit unacceptable decline, whichever criterion occurs first. Use of both methods will provide the designer with the best information for selection of appropriate compaction time. Examples of test results are shown in Figures 4 and 5. Figure 4 shows the effect on set time by the addition of different doses of a retarder and the use of fly ash.

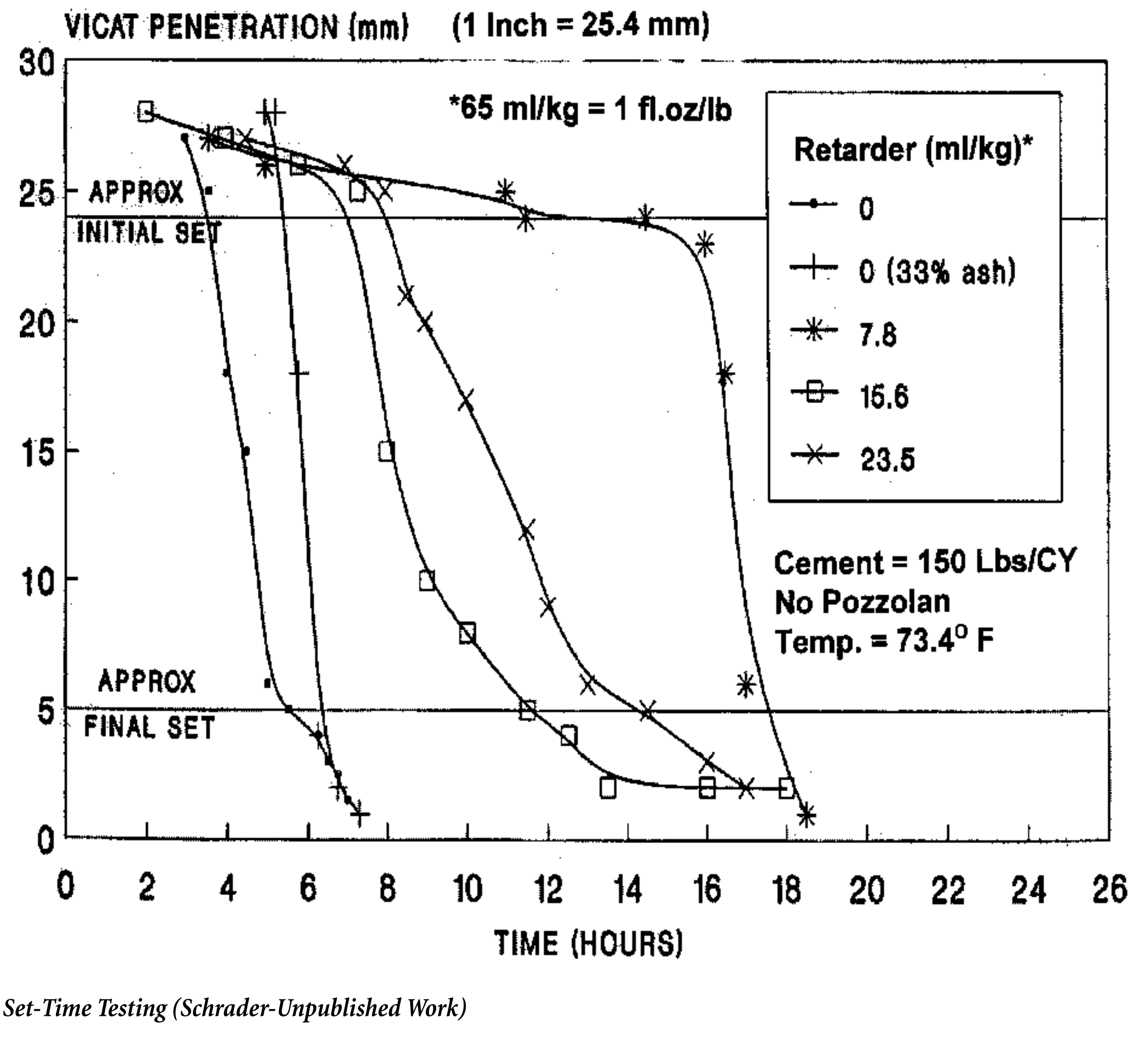

Figure 4. Set-Time Testing (Schrader-Unpublished Work)

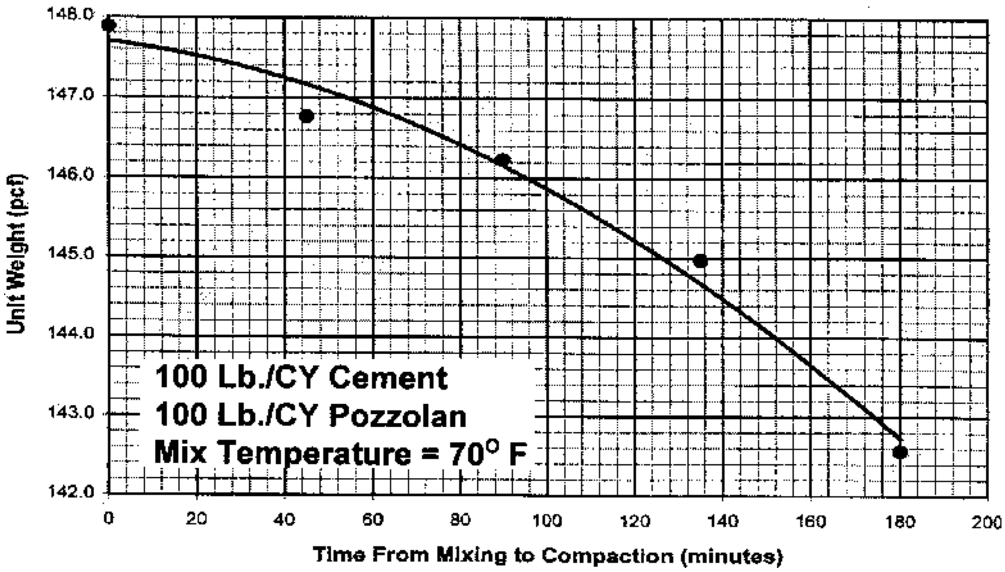

Figure 5. Unit Weight vs. Time of Compaction (Holderbaum-Unpublished Work)

Figure 5 indicates that for the tested mix a 45-minute limit to time of compaction might be reasonable.

During the mix design, if additional time would provide a benefit to the contractor, a mix could be developed that has a longer initial set time. Retarders have been used successfully in RCC mixes to increase set times. Sometimes the liberal use of fly ash and other admixtures, such as water reducers and air entraining agents, can retard the initial set. Figure 6 shows the results of a study on the effect delayed compaction and temperature have on compressive strength for two RCC mixes.

Time of compaction is an important quality control requirement and the engineer should be conservative if no laboratory-testing program is conducted.

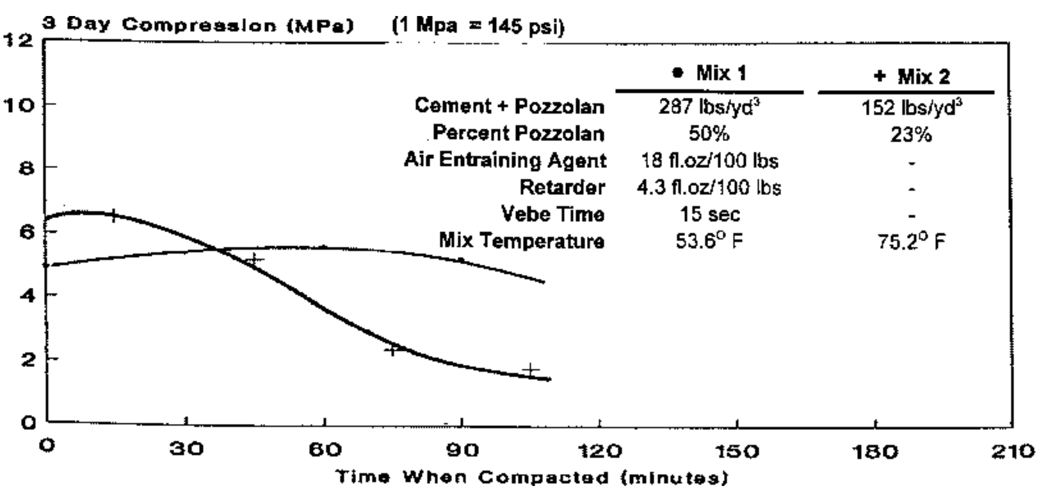

Figure 6. Compressive Strength vs. Time of Compaction (Schrader-Unpublished Work)

Decisions Regarding Additional Compaction and Removal: If a failing density test is obtained, the RCC may be re-rolled if the compaction time has not been exceeded. Compaction performed beyond the allowable compaction time should be avoided as the RCC can be damaged. Low densities may be the result of segregation or improper moisture content, in which cases additional rolling will not increase density. A single failing density test does not necessarily indicate the need for removal of RCC. A series of tests should be performed around the area in question to determine the extent of the low-density area. If removal is deemed necessary, these tests can be used to determine the limits of removal.

It is not uncommon for portions of an RCC lift to be removed during construction because the minimum target density could not be achieved. Because removing RCC that has already been compacted is time consuming and may halt RCC production, the decision to require removal should not be made in haste, and all consequences must be considered. The decision process must consider whether the low-density RCC, if left in place, would compromise the integrity of the structure. If the area in question has a density slightly lower than the target and is limited in area, in most cases it can be left in place. This is particularly true if prior cylinder breaks are known to exceed the design strength. For further guidance, the engineer may want to perform compressive strength testing on low-density cylinders as part of the mix design process or during the early stages of construction. All evidence should be considered before removal of RCC is directed. Removing RCC may do more harm than good by the very nature of the removal process.

Standby Compaction Equipment: The requirement to have standby rollers available within 30 minutes is usually not necessary for low volume projects. However, if breakdowns are frequent, the owner may be left with added costs for QA/QC inspections.

LIFT AND CONTRACTION JOINTS (Specification Paragraph 3.10)

Need for Contraction Joints: For most armoring projects, cracking of the RCC can be tolerated; therefore, the need to install contraction joints is minimized or not required. In addition, placement of RCC on fill material creates much less restraint than would occur on a rigid foundation, thereby allowing thermal contraction of the concrete to occur with minimal development of crack-producing stresses. For spillway projects, jointing may be necessary to control the size and layout of individual blocks. Decisions regarding jointing will depend on foundation conditions, weather conditions at the time of placement, and RCC mix properties.

Selection of Joint Spacing: If used, the spacing of joints should be determined by changes in foundation grade, structure or conduit locations, changes in RCC cross-section, and computed thermal stresses. The Corps of Engineers' ETL 1110-2-542, *Thermal Studies of Mass Concrete Structures*, provides guidelines and design examples for thermal analyses and selection of joint spacing for stress relief. Structures that are anchored on earth foundations will experience much less restraint than those on rock foundations. This factor should be considered when selecting joint spacing.

Selection of Cold Joint Requirements: The rate at which cold joints develop in any RCC structure is a function of the joint exposure time, the joint temperature, and the chemical properties of the cement and fly ash. The first two factors can be combined in a term called "lift joint maturity," usually expressed in degree-hours. A cold joint is determined to exist when a specified degree-hour limit is exceeded. Cold joint limits in specifications have typically ranged from 500 to 2000 degree F-hours. Selection of the appropriate value should be based on the joint properties required to satisfy the design. In general, shear strength can be expected to decrease with increased lift joint maturity and permeability can be expected to increase. The lift joint maturity degree-hours have little effect on the friction component of the shear properties at the lift joint, but as the degree-hours increase, the cohesion between the two lift surfaces decreases. If substantial cohesion is required between the two lifts to satisfy design criteria then one should tend towards the 500 degree-hours limit. If little cohesion is required, then the upper limit might be acceptable. Although these properties are not as critical as they are for design of a gravity dam, they should be considered when preparing the specifications. Published values of shear strength and permeability for selected mixes can be found in ACI Committee Report 207.5R.

On small projects or where occurrence of colds joints is not a significant problem, basing cold joint criteria on a set number of hours, as opposed to degree-hours, may be acceptable. This practice has been implemented on some projects and has simplified the process for both contractor personnel and the inspection staff. This procedure allows the contractor to better plan and schedule his labor and materials because he knows exactly when he has to be prepared to treat a cold joint.

REINFORCING STEEL AND ANCHOR BARS (Specification Paragraph 3.11)

Reinforcing Steel: Reinforcing steel is seldom incorporated into small RCC overtopping protection and spillway projects. In some cases, reinforcing steel has been incorporated in RCC to increase crack resistance at abrupt changes in grade, above conduits, and at other locations. While reinforcing can be accommodated in the placement, it should be avoided whenever possible. Placement of reinforcement, even when well planned, significantly slows RCC placement and may impact the in-place RCC properties to the point that the benefits of the reinforcing are completely negated. If reinforcing is absolutely necessary, the specifications should clearly describe the sequence of reinforcing and RCC placement. It is important that RCC be carefully placed around any steel to assure proper bond to the reinforcing is achieved. This is especially important when a lean dry RCC mix is used.

Anchor Bars: Steel anchor bars are commonly used to anchor precast concrete panels or cast-in-place concrete walls to RCC. Anchor bar installation can usually be accommodated with only minimal impact on the RCC placement operations. Threaded steel inserts should be installed in either the RCC or conventional concrete to facilitate installation of the anchor bars.

CURING AND PROTECTION (Specification Paragraph 3.12)

Moist Curing Methods: As with conventional concrete, RCC must be cured to develop anticipated properties. The preferable curing method is an application of a fine mist to the lift surface and/or slope. The application of water should be such that erosion of the lift surface does not occur.

Curing Compounds: At the discretion of the designing engineer, curing compounds may be acceptable on exposed surfaces if no additional concrete will be placed on the cured surfaces. Due to the open texture surface of RCC as compared to conventional concrete, curing compounds should be applied at a rate of at least 2 times the manufacturer's recommended dosage rate for conventional concrete and should be applied in 2 coats with the second coat applied perpendicular to the first coat. The designing engineer should consider the thermal benefits of curing with water and the need for such benefits for the particular application prior to allowing the use of curing compounds. Additional discussion is included in the commentary for Paragraph 3.01 under "Thermal Stress Considerations."

Protection: RCC must be protected from freezing during cold weather until placement of the next layer and for a specified period after completion of placement. The temperature of the RCC surface should be maintained above 35 °F. Surface temperature probes must be used to accurately measure the surface temperature. Large placement areas normally associated with embankment armoring are difficult to protect during cold weather; therefore, avoiding freezing conditions when establishing the placement schedule should be considered. If a winter shutdown is required for the project, 2 feet of lightly compacted earth fill material will usually provide sufficient protection against freezing, except in severe environments. High-pressure washing of the RCC surface will be necessary after removal of the earth fill, and a bedding mortar is usually applied prior to placement of the next RCC lift.

Curing and Protection Duration: The required duration of curing and protection should be compatible with the selected RCC mix design and anticipated strength gain. Seven (7) days should be considered a practical minimum curing and protection period. Figure 7 illustrates curing of a completed spillway slab using continuously wetted burlap.

Figure 7. Moist Curing with Burlap (Saltlick Dam Spillway Slab)

FACING FINISH TREATMENT (Specification Paragraph 3.13)

General: Exposed RCC has been generally used for the face of overtopping protection or spillway projects. The RCC mix must be designed to have sufficient durability and strength to withstand climatic and hydraulic forces to which it will be subjected. If it is determined that no exposed RCC mix can withstand these forces or may need to be more esthetically appealing, it may be faced with conventional concrete, precast concrete, or a combination of both. Another method of treating the downstream face that has gained considerable acceptance lately is to cover the RCC with earth and planted grass.

Expectations: Very few owners of RCC structures own more than one RCC project. The typical RCC project is sold to an owner as a concrete structure, but, because of construction methods, will be more economical than conventional concrete. Many owners envision their projects having fairly smooth textures and the straight lines of conventional concrete, only to be disappointed when they see the unfinished look of an RCC surface. Prospective owners should be shown examples of unfaced RCC surfaces and the different methods that have been used to face RCC to increase durability and to improve appearance. If the owner's expectations are known at the beginning of the design process, certain steps can be taken to improve the finished appearance of unfaced RCC, if required. Mixes with a high paste volume and finer aggregate gradation can be used to fill surface voids, minimize segregation, and reduce the occurrence of rock pockets.

Selection Criteria: Facing system selection is site specific and should consider the intended purpose of the facility, local climatic conditions, materials availability, dam size, and owner preferences. An overview of the various facings systems that have been used, including assessments of performance of each type of system, is presented herein. Guidelines are also provided for selection of the appropriate systems with consideration for constructability, durability, appearance, and cost. Although the type of facing system selected is site specific and is based on a number of criteria, all successful facing systems for RCC have one feature in common—they should not impede the high production rates of RCC placement. This should always be a consideration in selecting a facing system for an RCC project.

Available Facing Options: The selection of the downstream RCC facing system is primarily concerned with constructibility, aesthetics, and sometimes energy dissipation of overtopping flows. Here again the designer must consider the intended purpose of the facility, local climatic conditions, materials availability, dam size and shape, and owner preferences. Typical sections of the five most common downstream facing systems used in the construction of RCC dams are presented in Figure 8. Each of these facing systems is discussed below.

Unformed RCC. An unformed RCC face generally can be constructed on RCC dams where the downstream slope is flatter than 0.8H: 1 .0V. To improve constructability, or when natural rounded aggregates are used, a slope of 0.85H: 1 .0V, or flatter, should be considered. Steeper slopes require downstream forms to maintain the slope as the natural angle of repose of the RCC mix is exceeded. The angle of repose of an RCC mix mainly depends on the shape and grading of the aggregates, and mix workability. When using an unformed RCC face, the face is normally overbuilt 1 to 2 feet for long-term loss of RCC due to weathering. This allowance accounts for the fact that it is difficult to achieve a high degree of compaction on the exposed RCC slope, resulting in lower density and lower strength at the face. As weathering progresses and the weaker, less dense RCC is removed, the stronger, more dense RCC is exposed. Attempts to compact the exposed slope have included motorized hand compactors, running the wheels of heavy equipment along the outer edge, and using specially designed compaction equipment mounted on hydraulic tractors.

During construction, spillage over the downstream face is expected to occur, which will result in an accumulation of loose uncompacted RCC at the face and along the toe. It will probably have little or no cemented value.

A common feature of RCC faces that have been constructed with an unformed downstream face is the emergence of vegetation on the face after several years. The vegetation can be especially prolific and dense where the face is kept wet from seepage or surface runoff.

Public and owner perception of the exposed RCC face must also be considered when using this facing system. Even though the RCC section is designed to accept loss of some of the downstream face through weathering, public and/or owner perception of the rough concrete surface may draw unnecessary criticism and alarm.

Formed RCC. Use of forms to construct the downstream face has primarily been employed where the downstream RCC slope is steeper than 0.8H:1 .0V, and/or where a stepped surface is desired for energy dissipation of overtopping flows or for appearance. To improve the density and surface appearance at the formed RCC face, a wedge of bedding mix can be placed against the downstream form prior to placing the RCC. The dozer operator can spread the RCC against the form in a manner that causes the bedding mix to ride up the face of the form. If the RCC is then carefully compacted, the texture of the finished face can approach that of conventional concrete.

Unreinforced concrete placed concurrently with RCC. This facing system is very similar to the formed RCC facing system, except that a strip of unreinforced conventional concrete 2 to 3 feet wide is placed against the downstream form prior to placing and compacting the RCC. The RCC is spread and compacted into the conventional concrete. The conventional concrete face is generally more durable and attractive than a formed RCC face. If the formed steps are left exposed after construction, the tread of the step can be sloped to prevent water from ponding on the steps. A disadvantage of this system is that it can be difficult to coordinate delivery and placement of the two different concrete materials.

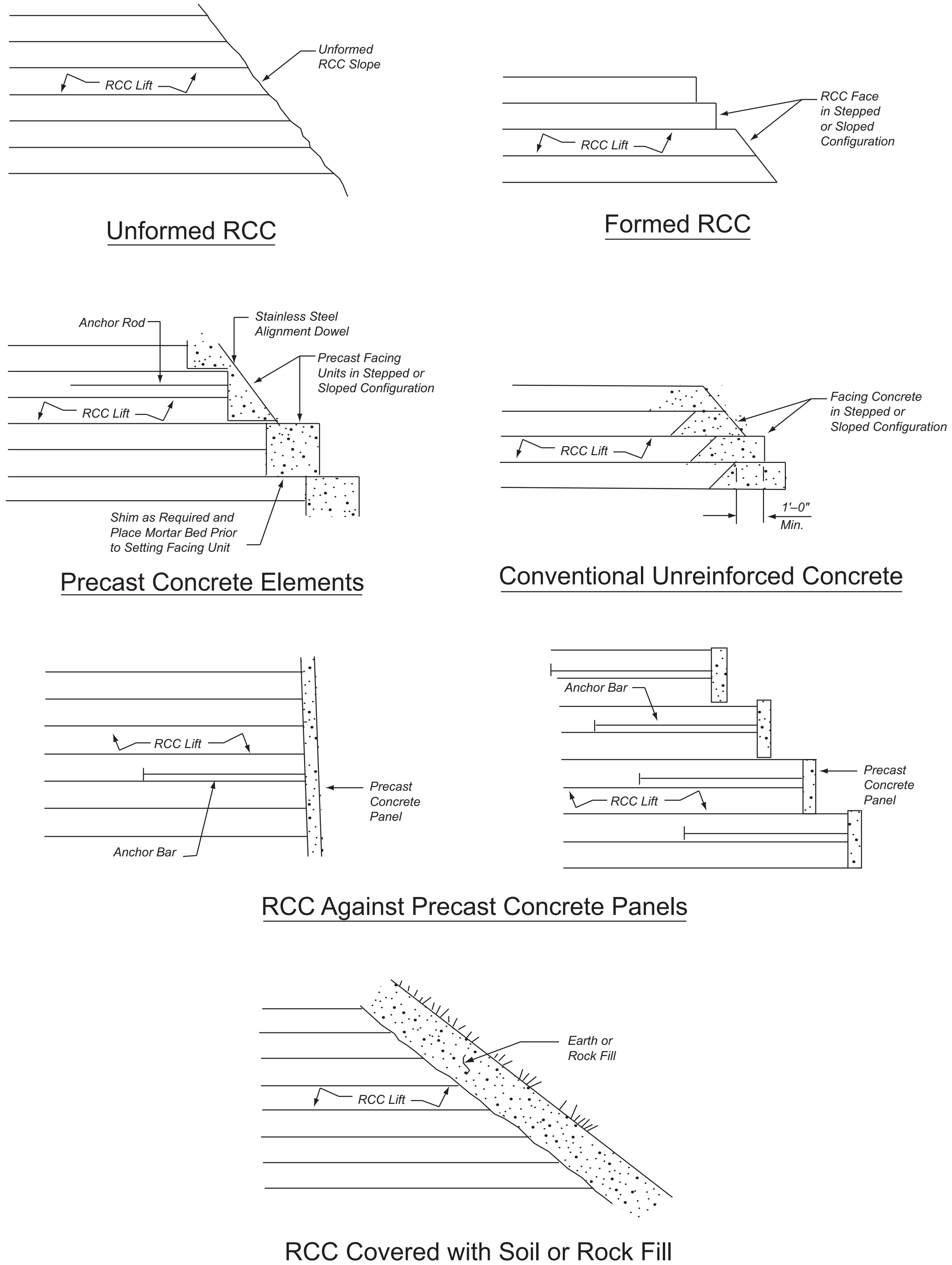

Figure 8. Downstream Facing Systems

Precast concrete elements. Precast concrete elements were first used in 1984 to construct the downstream face of the North Loop Detention dam in Texas. Appearance was an important issue for the dams that were part of a business park development. In addition to forming the downstream face of the dams, the precast concrete panels were used to form a three-level continuous planter across the downstream face. Each precast unit is tied to the RCC with anchor rods that are threaded into an insert cast in the unit and embedded in a lift of RCC. Precast facing units also provide an economical stay-in-place form that is both durable and aesthetically pleasing.

RCC covered with earthfill. The soil fill covering the downstream face of the RCC protects the untreated RCC face from weathering, provides a thermal blanket to reduce cracking from thermally induced stresses, and increases the sliding and overturning safety factors for the dam. The fill can be seeded to provide an aesthetic appearance.

Selection Guidelines: It should be recognized that a downstream facing system that is suitable for one dam rehabilitation or spillway project might not be adequate for other dams. Table 2 is presented as a general guide to help select one of the five downstream facing systems discussed. The evaluations for each factor presented in Table 2 are based on the performance of the facing system at existing dams, experience, and judgment. Each of the facing systems was evaluated for four factors: cost, appearance, durability, and constructability.

TABLE 2: Design Factor Ratings for Downstream Facing Systems

Facing System	Cost	Appearance	Durability	Construct-ibility
1. Unformed RCC	Low	Poor	Fair	Routine
2. Formed RCC	Moderate	Fair	Fair	Routine
3. Unreinforced Concrete Placed Concurrently with RCC	Moderate	Fair	Good	Difficult
4.. Precast Concrete Elements	Moderate	Good	Good	Difficult
5. RCC Covered with Earthfill	Low	Good	Good	Routine

INSTRUMENTATION (Specification Paragraph 3.14)

Common Types of Instruments: In general, instrumentation should be minimized for most armoring and spillway projects. The following types of instruments have been used:

Thermocouples. For large structures or where thermal cracking is an issue, thermocouples have been installed to monitor temperature rise. They are economical and easily installed. Thermocouples have been placed in the aggregate stockpiles to help better manage the withdrawal of the aggregate for RCC mix temperature control.

Piezometers. Piezometers have been installed beneath spillway slabs to measure uplift pressures. If the structure is designed for “full uplift,” the data is primarily of academic interest and the instruments could be eliminated, thereby avoiding additional project costs. If the structure is designed for less than “full uplift,” piezometers may be required to verify that the project is performing as intended.

Monuments and measuring pins. Monuments and measuring pins have been installed to monitor structure movement and to determine long-term material loss resulting from either freeze-thaw deterioration or erosion. These provide information for performance evaluation and for scheduling future maintenance.

Conflicts with RCC Placement: All of the instruments previously described can be installed with minimal or no impact on RCC placement if proper instruments are selected and an acceptable construction sequence is adopted.

STRUCTURAL TOLERANCES (Specification Paragraph 3.15)

Line and grade tolerances for completed RCC surfaces need to be realistic considering the means and methods used in RCC construction. Tight survey controls will minimize major defects, but straight lines and grades should not be expected. The specifications should be written to require a sturdy forming system that will prevent bulges in steps and other exposed faces due to the dynamic compaction adjacent to the forms.

QUALITY CONTROL AND TESTING (Specification Paragraph 3.16)

General: Although quality control responsibility for many small projects is often assigned completely to the contractor, the engineer and contractor should work together to develop an acceptable and project specific Quality Control Program. The contractor's daily costs during RCC placement are relatively high compared to other project activities; therefore, the program should be well defined in advance of the start of placement, including required action(s) when failing tests occur. The party responsible for performing each test or activity should be defined in the specifications. The responsibility may depend on the party responsible for developing the RCC mix design(s). See Section titled "MIX DESIGNS" for more discussion on this issue.

Contractor Responsibility: Certain activities such as concrete plant calibration, concrete plant control, scale calibration, and testing of compaction equipment should always be the responsibility of the contractor. Additional quality control responsibility beyond these "core activities" may also be assigned to the contractor. However, where available contractors are unfamiliar with RCC, particularly on small projects, it may be beneficial for the owner or design engineer to perform some of the tests and inspections that would normally be assigned to the contractor on a larger project.

Owner Responsibility: The owner, or the owner's designated representative, is typically responsible for performing some of the quality control testing and all quality assurance activities. This work is typically assigned to the design engineer or a construction manager engaged by the owner.

Engineer Responsibility: Design engineers are responsible for the design and performance of the project regardless of their responsibility for quality control and testing during construction. Accordingly, it is often in the designer's interest to be actively involved through all phases of construction. (Note: It is the authors' opinion that it is also in the owner's interest to have the design engineer actively involved with quality control and assurance during construction. The designer understands the intent of the design and is better suited to assist the owner with critical decisions, particularly when problems arise.) If the design engineer develops the RCC mix design(s) it may be in his best interest to also perform testing during construction to confirm that project design criteria have been met, rather than leaving the testing to someone who, when working for the contractor, may be influenced by production goals.

QC Program Modification: The quality control program should be developed with flexibility to permit modification of the program in response to observed conditions or changes in schedule.

LABORATORY AND TESTING FACILITIES

Laboratory and testing equipment requirements will vary depending on the size and complexity of the project. As a minimum, equipment and facilities should be provided on-site for in-place density testing and moisture content testing, as well as preparing and molding and curing of cylinders for compressive strength testing. Equipment for determining gradation of aggregates is also desirable but not essential if aggregates are provided by a reliable commercial producer and if tests are performed on the material by an independent laboratory.

MEASUREMENT AND PAYMENT (Specification Part 4)

General: Measurement and payment for RCC placed in embankment armoring or spillway projects may be on either a lump sum or unit price basis. In most projects, unit price basis is the preferred method because it allows more flexibility to make changes to the design mix.

Unit Price Contracts: If variation in quantities is anticipated, a unit price contract provides the greatest flexibility. Many contracts are written with provisions for unit price adjustments if quantities change more than 15% or 20%, while other contracts do not permit such change under any circumstances. The engineer should assess the potential for quantity changes and determine if such provisions are appropriate. When unit price contracts are used, the need for individual payment items for aggregates; cement; pozzolan (if used); mixing, conveying, and placing RCC; trial placement; bedding mix; contraction joints; and winter protection (if required) should be assessed and included in the bid documents as appropriate.

Lump Sum Contracts: Lump sum contracts are best used where little or no variation in quantities is anticipated. However, lump sum contracts can also be used in cases where quantities may vary, provided that supplemental or contingent payment items are included in the contract for those items that are expected to vary in quantity. Descriptions of contingent or supplemental pay items should be provided in the bid documents.

Note: This document is written in English units. To convert to metric untits use the conversion table presented below.

Selected Conversion Factors to SI Units

To Convert	Into	Multiply by
Square yard (yd^2)	Square meter (m^2)	0.8361
Square foot (ft^2)	Square meter (m^2)	0.0.0929
Foot (ft)	Meter (m)	0.3048
Inch (in.)	Millimeter (mm)	25.4
Ton (2000 lb)	Kilogram (kg)	907.185
Pound (lb)	Kilogram (kg)	0.45359
Pounds per square inch (psi)	Kilopascals (kPa)	6.8948
Cubic yard (yd^3)	Cubic meter (m^3)	0.7646
Horsepower (HP)	Kilowatt (kW)	0.7457
Fahrenheit (°F)	Celsius (°C)	5/9 (°F – 32)
Cubic foot (ft^3)	Liter (L)	28.316
Gallon (U.S.)	Liter (L)	3.785
Fluid ounce per pound (fl.oz./lb)	Milliliter per kilogram (mL/kg)	65.2

Portland Cement Association
5420 Old Orchard Road
Skokie, Illinois 60077-1083
847.966.6200 Fax 847.966.9781

500 New Jersey Avenue NW, 7th Floor
Washington, DC 20001-2066
202.408.9494 Fax 202.408.0877
www.cement.org

An organization of cement companies to improve and extend the uses of portland cement and concrete through market development, engineering, research, education and public affairs work.

EB214.02