

## **Roller-Compacted Concrete Pavements as Exposed Wearing Surface**

Version 1.2 – September 4, 2014

This document provides a guideline specification useful for developing project specifications for roller compacted concrete (RCC) as an exposed RCC pavement surface, that may or may not be diamond ground for smoothness and/or texture. RCC as a base/subbase layers is not covered in this specification. The information is also not wholly applicable for non-pavement applications such as backfills, dams or liners. This guideline should not be used as a specification reference in contract documents. An owner, engineer or contractor must consider the available options and apply these guidelines to create specifications for specific local projects.

This document references appropriate material standards, test methods and specifications of American Association of State Highway and Transportation Officials (AASHTO), ASTM International (ASTM), and Canadian Standards Association (CSA). These references assume that the contractor and the engineer will use the most up-to-date and applicable standards or methods that are in effect when bids are solicited for the project. It also assumes that the specification writer will choose the standard or test most suitable for their agency/project.

Footnotes accompany many of specification provisions herein. These added details describe reasoning for certain specification features, as well as provide considerations and important information for the specification writer.

### **ACPA's ROLLER-COMPACTED CONCRETE TASK FORCE**

The following individuals serve on the ACPA RCC Task Force as members or friends, and have contributed their expertise, experiences and efforts to create this guideline:

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## APPLICABILITY

This guide specification is directly applicable to roller-compacted concrete (RCC) as a pavement surface, that may or may not have diamond grinding applied to it. Available options provide the specification writer flexibility to tailor provisions specifically for an array of projects, including:

- Heavy-duty applications, such as:
  - Ports
  - Military installations
  - Intermodal facilities
- Light industrial applications, such as:
  - Warehouses
  - Manufacturing facilities
  - Commercial parking lots
  - Maintenance and storage yards
- Roadway applications, such as:
  - Highway shoulders
  - Local streets and roads

## BACKGROUND ON ROLLER-COMPACTED CONCRETE

To achieve a successful project, it is important that the specification writer distinguish RCC from conventional concrete, and apply the provisions of this specification that are most appropriate for their application. RCC is essentially portland cement concrete. However, it is engineered and constructed differently than conventional concrete and requires different placement and design considerations even though it is made of the same constituent materials: aggregate, portland cement, supplementary cementitious materials, chemical admixtures and water.

Although made of similar materials, RCC pavements are unlike conventional concrete pavements in many ways, especially during production and placement. Therefore, it is important for the specification writer to be keenly aware of these differences while developing RCC specifications, including:

- RCC requires placement with asphalt-type pavers. It is not placed with typical slipform concrete paving machines.
- RCC mixtures require compaction with the use of vibratory, tamper bar screeds, and subsequently, with vibratory rollers to achieve a target density. RCC does not require the internal vibration necessary to consolidate conventional concrete.
- RCC has little to no slump. Conventional concrete paving mixes require between 1-in (25 mm) and 4-in (100 mm) of slump depending on placement method.
- RCC mixtures require different mixing considerations than conventional concrete mixtures. RCC mixtures are relatively dry compared to conventional concrete mixtures and depend on stability in the plastic state to support rollers for compaction.
- RCC mixtures do not usually require air entrainment for freeze/thaw durability. The experience from past projects indicate that it is not necessary, however additional study is continuing.
- Due to its dry nature, RCC pavements do not allow for or require finishing operations like conventional concrete pavement.
- RCC pavements are not surface textured in a plastic state like conventional concrete pavement, however, they can be surface textured through grinding or grooving like conventional concrete pavements.
- The surface of an RCC pavement does not resemble the surface of a conventional concrete. Rather an RCC surface is more inconsistent and typically includes minor surface tearing, checking, pitting or pockmarks. It more closely resembles an asphalt pavement surface.
- RCC pavement, unlike conventional concrete pavement, cannot be reinforced with steel nor include dowel bars to provide joint load transfer because there is no way to insert the steel during construction. Joint load transfer must rely on aggregate interlock and base support for long-term joint performance.

## SCOPE OF THIS GUIDELINE

This guideline includes all of the provisions necessary to create an RCC pavement project specification. Specification language and helpful commentary cover appropriate provisions and descriptions for proportioning, mixing, placing, compacting, and curing concrete for RCC

applications. Specific placement provisions ensure that an RCC pavement conforms to the lines, grades, thickness, and typical cross section details required in project plans or detail drawings. The specification writer should incorporate appropriate project details and assumptions into the project specification developed using this guideline. It is recommended to consult with your local or national ACPA representative for any advice on developing a project specification.

## APPLICABLE MATERIAL AND TESTING STANDARDS

### AASHTO:

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|             |                                                                                                                           |
|-------------|---------------------------------------------------------------------------------------------------------------------------|
| <b>M6</b>   | Standard Specification for Fine Aggregate for Portland Cement Concrete                                                    |
| <b>M80</b>  | Standard Specification for Coarse Aggregate for Hydraulic Cement Concrete                                                 |
| <b>M85</b>  | Standard Specification for Portland Cement                                                                                |
| <b>M148</b> | Standard Specification for Liquid Membrane-Forming Compounds for Curing Concrete                                          |
| <b>M194</b> | Standard Specification for Chemical Admixtures for Concrete                                                               |
| <b>M240</b> | Standard Specification for Blended Hydraulic Cement                                                                       |
| <b>M295</b> | Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete                          |
| <b>M302</b> | Standard Specification for Slag Cement for Use in Concrete and Mortars                                                    |
| <b>T26</b>  | Standard Method of Test for Quality of Water to Be Used in Concrete                                                       |
| <b>T99</b>  | Standard Method of Test for Moisture-Density Relations of Soils Using a 2.5-kg (5.5-lb) Rammer and a 305-mm (12-in.) Drop |
| <b>T180</b> | Standard Method of Test for Moisture-Density Relations of Soils Using a 4.54-kg (10-lb) Rammer and a 457-mm (18-in.) Drop |

### ACI:

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|            |                                                 |
|------------|-------------------------------------------------|
| <b>214</b> | Evaluation of Strength Test Results of Concrete |
|------------|-------------------------------------------------|

### ASTM:

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|             |                                                                                          |
|-------------|------------------------------------------------------------------------------------------|
| <b>C31</b>  | Practice for Making and Curing Concrete Test Specimens in the Field                      |
| <b>C33</b>  | Standard Specification for Concrete Aggregates                                           |
| <b>C39</b>  | Test Method for Compressive Strength of Cylindrical Concrete Specimens                   |
| <b>C42</b>  | Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete          |
| <b>C78</b>  | Test Method for Flexural Strength of Concrete (Using Simple Beam with 3rd Point Loading) |
| <b>C94</b>  | Standard Specification for Ready-Mixed Concrete                                          |
| <b>C150</b> | Standard Specification for Portland Cement                                               |
| <b>C171</b> | Standard Specification for Sheet Materials for Curing Concrete                           |
| <b>C309</b> | Standard Specification for Liquid Membrane-Forming Compounds for Curing Concrete         |
| <b>C494</b> | Standard Specification for Chemical Admixtures for Concrete                              |

- C496** Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens
- C566** Test Method for Total Evaporable Moisture content of Aggregate by Drying
- C595** Standard Specification for Blended Hydraulic Cements
- C618** Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete
- C685** Standard Specification for Concrete Made by Volumetric Batching and Continuous Mixing
- C989** Standard Specification for Slag Cement for Use in Concrete and Mortars
- C1040** Test Method for Density of Unhardened and Hardened Concrete in Place by Nuclear Methods
- C1077** Standard Practice for Agencies Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Testing Agency Evaluation
- C1170** Standard Test Method for Determining Consistency and Density of Roller-Compacted Concrete Using a Vibrating Table
- C1157** Standard Performance Specification for Hydraulic Cement
- C1176** Standard Practice for Making Roller-Compacted Concrete in Cylinder Molds Using a Vibrating Table
- C1240** Standard Specification for Silica Fume Used in Cementitious Mixtures
- C1435** Practice for Molding Roller-Compacted Concrete in Cylinder Molds Using a Vibrating Hammer
- C1602** Standard Specification for Mixing Water Used in the Production of Hydraulic Cement Concrete
- D698** Standard Method of Test for Moisture-Density relations of Soils Using a 2.5-kg (5.5-lb) Rammer and 305-mm (12-in.) Drop.
- D977** Standard Specification for Emulsified Asphalt
- D1557** Test Method for Laboratory Compaction Characteristics of Soil Using Modified Effort
- E329** Standards of Recommended Practice for Inspection and Testing Agencies for Concrete, Steel, and Bituminous Materials as Used in Construction.

**CSA:**

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- CSA A23.1/A23.2** Concrete Materials and Methods of Concrete Construction/Test Methods and Standard Practices for Concrete
- CSA A3001** Cementitious Materials for Use in Concrete

## TERMINOLOGY

**Approval:** Written authorization or acceptance from the Engineer prior to starting an activity.

**Construction Stakes, Lines, and Grades:** The Engineer positions construction stakes to establish lines and grades for street work and for structures; the Engineer stakes the centerline and furnishes bench marks necessary to correctly lay out the pavement. The contractor maintains these lines, grades, and bench marks and uses them to lay out the work under the contract. The contractor must carefully preserve stakes and bench marks.

**Contractor:** The contracted construction firm or its subcontractor hired to perform all or part of the work under the contract specifications and drawings.

**Design Strength:** The strength used by the designer in the thickness design method or software to determine the RCC Plan thickness. (The design strength should be the expected average field strength, which is necessarily higher than the minimum specified strength.)

**Engineer:** The owner or an agent of the owner that issues drawings and specifications, or administers the work under contract specifications and drawings, or both.

**Intent of the Contract:** For the contractor to build the pavement in accordance with the specification and in reasonably close conformity with the lines, grades, thickness, and typical cross sections shown in the project plans or as established by the engineer/owner. Construction methods are generally left to the discretion of the contractor, as long as progress and workmanship are satisfactory.

**Lot:** Term used for acceptance testing, representing the pavement/material placed in a maximum area or volume specified for quality assurance testing; placed in one day; placed with one construction method; or with one unique mixture.

**Maximum Dry Density (MDD):** The maximum unit weight (density) of an RCC mixture corresponding to the optimum moisture content typically determined per ASTM D1557.

**Optimal Moisture Content (OMC):** The water content at which the maximum dry unit weight (density) is achieved for a specific compaction effort, typically determined per ASTM D1557.

**Plan Thickness:** The nominal pavement layer thickness shown in the Plans.

**Reference Wet Density (RWD):** The unit weight density calculated by multiplying the Maximum Dry Density (MDD) by  $1 + \text{Optimum Moisture Content (OMC)}$ , where the MDD and OMC are determined in the laboratory in accordance with ASTM D1557. [Example: assume an RCC mix has a Modified Proctor MDD of  $142 \text{ lb/ft}^3$  ( $2,275 \text{ kg/m}^3$ ) and the OMC = 6%. The calculated RWD =  $142 \cdot (1+(0.06)) = 150.5 \text{ lb/ft}^3$  or in SI Units:  $\text{RWD} = 2,275 \cdot (1+(0.06)) = 2,412 \text{ kg/m}^3$ ].

**Sublot:** The volume, area or lineal quantity requiring a sample test(s) for acceptance.

**Supplementary Cementitious Materials:** Mineral admixtures consisting of powdered or pulverized materials which are added to concrete before or during mixing to improve or change some of the plastic or hardened properties of concrete. Materials are generally natural or by-products of other manufacturing processes, such as fly ash, silica fume, metakaolin, or ground-granulated blast-furnace slag that reacts pozzolanically or hydraulically.

**Testing Laboratory:** An organization that measures, examines, performs tests, or otherwise determines the characteristics or performance of materials or products. This may include organizations that offer commercial testing services, an in-house quality control function, or other organization providing the required testing services. These firms must meet requirements of ASTM C1077, “Standard Practice for Laboratories Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Laboratory Evaluation.”

**Testing Technician:** Person or persons that are either engineers, engineering technicians, or experienced craftsman with qualifications to perform tests.

**The Plans:** The drawings, diagrams, details or standards describing the dimension, elevation, form, location or size of the pavement or any of its components, including the foundation and any existing infrastructure.

## REFERENCES

1. Subgrades and Subbases for Concrete Pavements” EB204P, American Concrete Pavement Association, Rosemont, IL, 2007.
2. Guide for Roller-Compacted Concrete Pavements, SN298, National Concrete Pavement Technology Center, Ames, IA, August 2010.
3. Guide Specification for Construction of Roller-Compacted Concrete Pavements, IS009, Portland Cement Association, Skokie, IL, June 2004.
4. Report on Roller Compacted Concrete Pavements, 325.10R-95, American Concrete Institute, Farmington Hills, MI, 1995.
5. Guide to Evaluation of Strength Test Results of Concrete, ACI 214R-11, American Concrete Institute, Farmington Hills, MI, April 2011.
6. RCC Specification, Georgia Department of Transportation
7. RCC Specification, Kansas Department of Transportation
8. RCC Specification, Kentucky Transportation Cabinet
9. The Indiana Local Technical Assistance Program Roller Compacted Concrete Pavement Manual For Local Government Agencies, TR-2-2010, Indiana LTAP Center, Purdue University School of Civil Engineering, Nov. 2010.
10. Supplemental Specification 1523 Roller Compacted Concrete Pavements (RCC), City of Columbus, Columbus, OH, Feb. 2009.
11. Suggested Specification for Roller Compacted Concrete Paving For Municipal and Industrial Applications, Tennessee Ready Mixed Concrete Association.
12. RCC Specification, City of Edmonton, Alberta, Canada, October 2009.
13. Specification for Roller Compacted Concrete (RCC) Pavements, City of Burrton, Kansas
14. “Utility Cuts in Concrete Pavements,” IS235P, American Concrete Pavement Association, Rosemont, IL, 2009.

# GUIDE SPECIFICATION

## 1.0 General

**RCC-1.01 Description of Work.** This work consists of constructing roller compacted concrete pavement as an exposed pavement surface on a prepared base or subgrade layer.<sup>1</sup> The final surface may or may not be diamond ground, milled or grooved depending on the application, and smoothness and texture requirements.

**RCC-1.02 Prequalification<sup>2</sup>.** Submit the information required in RCC-1.02.1 to RCC 1.02.2 for prequalification to perform the work on this project.

**1.02.1 Completed Project Listing.** Provide evidence of successful installation of RCC pavement on <insert number<sup>3</sup>> prior projects of comparable size and application. Include a brief project description for each project as well as the final contract amount, the owners name and contact information, and the design engineer's name and contact information for each project listed.

**1.02.2 Proposed Installation Equipment.** For prequalification, supply a list of the proposed installation equipment, including mixing plant, paving equipment, and compaction equipment. Include the make, model, and equipment specification sheet for each piece of equipment with the prequalification submittal. Make the equipment available for inspection by the Engineer upon request.

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<sup>1</sup> **Note to specification writer** – For recommendations and specification language regarding preparation of natural subgrade, stabilized soil, aggregate subbase, consult appropriate passages in “Subgrades and Subbases for Concrete Pavements” ACPA Document EB204P (see Reference 1) or the local state or provincial standard specifications. When specifying the trimming tolerance for the prepared subgrade and subbase, it is important to make sure that tolerances are compatible to the RCC thickness requirement. That is, the thickness, grade elevation, and smoothness requirements must be compatible so the pavement can be constructed. For example, one cannot have a subbase requirement that is  $\pm 1$ -inch (25 mm), grade elevation tolerance that is  $\pm \frac{1}{2}$  -inch (12.5 mm), and thickness requirement that is  $\pm \frac{1}{4}$  -inch (6 mm), because if the subbase is 1 inch high, and the grade elevation is  $\frac{1}{2}$  inch low, it automatically means that the pavement will be thin in certain areas.

<sup>2</sup> **Note to specification writer** – There are several potential alternatives to determining whether a contractor is qualified to construct an RCC pavement. This guideline provides a provision to require a list of previous project experiences. Other options to consider include: (1) contractor has crew members with previous experience with RCC methods and a means for construction of projects of comparable size and application; (2) the contractor is working with a consultant that has experience with RCC methods and means of construction on projects of comparable size and scope; and (3) the contractor has provided adequate information on previous experience on non-RCC projects of similar size along with detailed work plans, equipment, construction process, project training, and explanation of how they plan to complete the project.

<sup>3</sup> **Note to specification writer** – Consider varying the number of reference projects you require based on your project's size or complexity. For bigger or more complicated projects, you should increase the number of previous projects required in order to assure the contractor has adequate experience.



## 2.0 Materials

**RCC-2.01 Material Requirements.** Furnish materials conforming to the latest version of the standard material specifications in Table RCC-1, as appropriate. Only furnish materials from sources approved by the Engineer.

**Table RCC-1<sup>4</sup>**

| Material                                                     | Specification(s) |       |        |
|--------------------------------------------------------------|------------------|-------|--------|
|                                                              | AASHTO           | ASTM  | CSA    |
| Aggregate – Coarse                                           | M80              | C33   | A23.1  |
| Aggregate – Fine                                             | M6               | C33   | A23.1  |
| Chemical Admixtures                                          | M194             | C494  | A266.2 |
| Concrete - Made by Volumetric Batching and Continuous Mixing | —                | C685  | —      |
| Concrete – Ready Mixed                                       | —                | C94   | A23.1  |
| Curing - Liquid Membrane-Forming Compounds                   | M148             | C309  | A23.1  |
| Curing – Sheet Materials                                     | —                | C171  | —      |
| Curing –Emulsified Asphalt                                   | —                | D977  | —      |
| Fly Ash or Calcined Natural Pozzolan                         | M295             | C618  | A3001  |
| Ground Granulated Blast Furnace Slag                         | M302             | C989  | A3001  |
| Hydraulic Cement (Performance Specification)                 | —                | C1157 | —      |
| Portland Cement                                              | M85              | C150  | A3001  |
| Portland Cement – Blended                                    | M240             | C595  | A3001  |
| Silica Fume                                                  | —                | C1240 | A3001  |
| Water                                                        | T26              | C1602 | A23.1  |

**RCC-2.02 Material Approval.** Prior to use, obtain the Engineer’s approval on all materials for RCC construction based on certifications and, where required, laboratory tests of representative samples of the materials that will be used in the actual construction.

**RCC-2.03 Aggregate Gradation.** Use a blend of fine and coarse fractions that in combination conform to the sieve size ranges listed in Table RCC-2, or size ranges approved by the Engineer.<sup>5</sup> Obtain all aggregates from qualified sources for concrete pavement appearing on the <insert state DOT or provincial ministry> qualified products listing, as well as conforming to requirements in Table RCC-1. Do not use an aggregate with a plasticity index exceeding five.

<sup>4</sup> **Note to specification writer** – Choose the appropriate material specifications for the project in consultation with the owner and/or your local ACPA or concrete industry representative. In Canada, use CSA standards. Default to ASTM specifications if no other recommendation exists.

<sup>5</sup> **Note to specification writer** – For quality RCC construction it is important not to hard fix the gradations. The contractor may need to make adjustments to fit local aggregate sources. Mixtures that have gradations outside the bands in Table RCC-2 may be acceptable if the contractor demonstrates to the Engineer that the RCC mixture meets all requirements of this specification, including density in the field.

**Table RCC-2: Combined Aggregate Gradation Ranges for RCC<sup>6</sup>**

| Sieve Size        | Lower & Upper Specification Limits<br>1/2 in (12.5 mm) |       | Lower & Upper Specification Limits<br>3/4 in (19.0 mm) |       | Lower & Upper Specification Limits<br>1 in (25.0 mm) |       |
|-------------------|--------------------------------------------------------|-------|--------------------------------------------------------|-------|------------------------------------------------------|-------|
|                   |                                                        |       |                                                        |       |                                                      |       |
| 1.5 in. (37.5 mm) |                                                        |       |                                                        |       | 100.0                                                | 100.0 |
| 1 in. (25 mm)     |                                                        |       | 100.0                                                  | 100.0 | 82.0                                                 | 100.0 |
| 3/4 in. (19 mm)   | 100.0                                                  | 100.0 | 95.0                                                   | 100.0 | 72.0                                                 | 95.0  |
| 1/2 in. (12.5 mm) | 81.0                                                   | 100.0 | 70.0                                                   | 95.0  | 61.0                                                 | 81.0  |
| 3/8 in. (9.5 mm)  | 71.0                                                   | 91.0  | 60.0                                                   | 85.0  | 50.0                                                 | 71.0  |
| No. 4 (4.75 mm)   | 49.0                                                   | 70.0  | 40.0                                                   | 60.0  | 36.0                                                 | 55.0  |
| No. 8 (2.36 mm)   | 33.0                                                   | 54.0  | 30.0                                                   | 50.0  | 25.0                                                 | 43.0  |
| No. 16 (1.18 mm)  | 24.0                                                   | 40.0  | 20.0                                                   | 40.0  | 15.0                                                 | 32.0  |
| No 30 (600 µm)    | 15.0                                                   | 30.0  | 15.0                                                   | 30.0  | 10.0                                                 | 26.0  |
| No 50 (300 µm)    | 10.0                                                   | 25.0  | 10.0                                                   | 25.0  | 5.0                                                  | 19.0  |
| No. 100 (150 µm)  | 2.0                                                    | 16.0  | 2.0                                                    | 16.0  | 2.0                                                  | 16.0  |
| No 200 (75 µm)    | 0.0                                                    | 8.0   | 0.0                                                    | 8.0   | 0.0                                                  | 8.0   |

<sup>6</sup> **Note to specification writer** – Aggregate quality and gradation is critical to RCC performance, because aggregate constitutes up to 85% of the volume of RCC. The aggregates greatly influence RCC fresh properties (e.g., compactibility and segregation potential), hardened properties (e.g., density, strength, shrinkage, void ratio, permeability, and long-term durability), and surface appearance.

Table RCC-2 provides several aggregate gradation options depending on the application, each allowing some ¾-inch (19-mm) aggregate. Typically smaller top-sized aggregates produce a tighter, better looking surface. However, the larger top-size aggregate ranges will typically produce higher strengths with less cement content than aggregates with a smaller top-size, and experienced contractors can produce closed surfaces using these aggregates. In selecting the final gradation, it is important to balance the need for a tight surface texture and increased load transfer capabilities. In general, it is easier to produce a consistent, tight (closed appearance) RCC surface and reduce segregation potential using a smaller nominal maximum aggregate size. For better load transfer a larger nominal maximum aggregate size and a stiffer base are important. For light load and local streets / road applications, where surface appearance is more of a concern, a tight surface texture requirement will likely control aggregate top-size for the mix design. For heavy load and industrial applications, load transfer is most likely the more important controlling factor.

For more information on RCC mixture design, see reference 2 as well as ACPA's gradation analyzer web application (<http://apps.acpa.org/apps/gradation.aspx>).

### 3.0 Quality Management Plan

**RCC-3.01 Quality Management Plan.**<sup>7</sup> Submit a quality management plan to the Engineer at least 30 days prior to start of paving operations. As a minimum include the following information in the quality management plan:

- 1) Organizational chart that identifies the key individuals assigned to production and placement operations. As applicable, include a project manager, RCC consultant, project superintendent, RCC production supervisor and quality control manager, or other positions as appropriate given the application. Include all appropriate contact data and the chain of command for decision-making.
- 2) List of subcontractors, including proposed job site personnel, for any construction operations.
- 3) Identification of the independent testing firm and qualifications of testing personnel.
- 4) Construction schedule for all RCC work.
- 5) List of all mixing, hauling, placing, compaction, curing and sawing equipment with manufacturer's data, specifications and certifications.
- 6) Outline of procedures for calibrating the mixing plant and monitoring materials during construction.
- 7) Plan for locating the mixing plant, required haul times to the furthest location of the placement, and use of set-retarding admixtures, if required to facilitate the delivery logistics.
- 8) Proposal for:
  - a. Lift thicknesses (if multiple lifts are necessary).
  - b. Paving width and staging plan.
  - c. Direction of paving operation.
  - d. Daily production, including trucking, placement and production rates.
  - e. Planned longitudinal and transverse cold joint locations.
  - f. Horizontal cold joint cleaning and preparation procedures.
  - g. Location and operation of mixing plant, including proposed mixing cycle time, drum capacity targeted per batch if using a drum-type mixing plant, cement and aggregate storage, and water supply on or off site.
- 9) Certification for aggregate source, quality and sizing as required by the appropriate material specification.
- 10) Certification of all cementitious materials and chemical admixtures as required by the appropriate material specification.
- 11) Outline of procedures and methods for curing and weather protection for cold [less than 40°F (4.5°C)], hot [more than 90°F (32°C)]<sup>8</sup> and rainy conditions.
- 12) Mixture design as outlined in Section 4.0.

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<sup>7</sup> **Note to specification writer** – For smaller projects, consider reducing the requirements for the Quality Management Plan based on local needs.

<sup>8</sup> **Note to specification writer** – In Canada use a cold weather threshold of 5°C and hot weather threshold of 27°C per CSA A23.1.

- RCC-3.02 Pre-Construction Meeting.**<sup>9</sup> Schedule a pre-construction meeting with the Engineer after submitting the quality management plan and prior to installation of a test section or the start of construction. Include project personnel identified in the quality management plan in the meeting, including but not limited to: general contractor representative/consultant, sitework contractor, RCC paving contractor, RCC plant manager, and construction testing laboratory representative.
- RCC-3.03 Records.** Maintain records of all certifications, tests, construction reports, material tickets, and remedial actions taken on the work. Supply the Engineer with all records upon request.
- RCC-3.04 Independent Testing Firm.** Only use an independent testing laboratory meeting the requirements of ASTM C1077<sup>10</sup> for preparing, handling, coring, storing and testing concrete specimens, who have the testing equipment necessary to carry out all proposed testing methods, and who can demonstrate adequate knowledge of the testing methods prescribed. Obtain the written qualifications of the testing firm, indicating their compliance with ASTM E329.<sup>11</sup> Obtain the most recent certificates of calibration for testing equipment, showing that the equipment has been calibrated at a minimum 12-month interval by devices of accuracy traceable to either National Bureau of Standards or an established value. Submit all certification records from the testing firm and equipment to the Engineer. Provide testing personnel access to the paving and plant sites for inspection and sampling of the RCC layer and constituent materials.
- RCC-3.05 Quality Control at Mixing Plant.** Conduct quality control testing at the mixing plant in accordance with the requirements in Table RCC-3. Obtain specimens, as required, for post-construction testing.

**Table RCC-3: Quality Control Requirements at Mixing Plant**

| Item              | Method                                              | Frequency or Lot Size                                                               | Acceptance                             |
|-------------------|-----------------------------------------------------|-------------------------------------------------------------------------------------|----------------------------------------|
| Plant Calibration | ASTM C685 for volumetric batch or continuous mixer; | Prior to start-up, after equipment changes, and after shutdowns longer than 14 days | Material tolerances given in ASTM C685 |
| Plant Calibration | ASTM C94 for central rotary drum mixer              | Prior to start-up, after equipment changes, and after shutdowns longer than 14 days | Material tolerances given in ASTM C94  |

- RCC-3.06 Quality Control at Placement Site.** Conduct quality control testing during placing operations to ensure the RCC material is placed, compacted, finished and cured in accordance with the requirements in Table RCC-4. Obtain specimens, as required, for post-construction testing.

<sup>9</sup> **Commentary** – The purpose of the pre-construction meeting is to review the information in the quality management plan and discuss the means, methods, sequences, techniques, communication protocol and procedures for installing the RCC pavement. A representative of the owner and the Engineer should participate in the meeting, along with relevant personnel, including the RCC consultant and subcontractors.

<sup>10</sup> **Note to specification writer** – In Canada use CSA A23.2-12C Making, Curing and Testing Compression Test Specimens of No-Slump Concrete.

<sup>11</sup> **Note to Specification writer** – In Canada use CSA A283-06(R2011) Qualification Code for Concrete Testing Laboratories.

**Table RCC-4: Quality Control Requirements at Placement Site<sup>12</sup>**

| Item                                                   | Method <sup>13</sup>                                                                                                            | Frequency or Lot Size                                                                                               | Limits                                                                                                                                                |
|--------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>RCC Moisture Content</b>                            | ASTM C566                                                                                                                       | Sample at point of placement from initial truck load, and as required                                               | ±1.0% of optimum moisture content per ASTM D1557                                                                                                      |
| <b>In-place Wet Mat Density</b>                        | ASTM C1040 direct transmission mode <sup>14</sup>                                                                               | At beginning of placement immediately behind the paver, and within 30 minutes of final compaction; One Test per lot | At least 98% of the laboratory reference wet density <sup>15</sup> by ASTM D1557 based on an average of four consecutive tests with no test below 96% |
| <b>In-place Wet Joint Density<sup>16</sup></b>         | ASTM C1040 direct transmission mode                                                                                             | One test per lot, and within 30 minutes after final compaction                                                      | At least 96% of the laboratory reference wet density <sup>15</sup> by ASTM D1557 based on an average of four consecutive tests with no test below 94% |
| <b>Cylinders for Compressive Strength<sup>17</sup></b> | ASTM C1435 for molding cylinders <sup>18</sup> ; ASTM C31 for curing and handling cylinders; and ASTM C39 for testing cylinders | One set of three cylinders for every lot, or one day of production, whichever is less.                              | Average strength equal to 100% of the specified strength in Sections RCC-4.03 and 4.04, with no single result below 90%.                              |
| <b>Surface Smoothness</b>                              | See Section 7.04                                                                                                                | One Test per lot                                                                                                    | See Section 7.04                                                                                                                                      |
| <b>Thickness<sup>19</sup></b>                          | ASTM C42                                                                                                                        | One core for every two lots, or one day of production, whichever is less.                                           | See Section 7.01                                                                                                                                      |

<sup>12</sup> **Note to specification writer** – Lot sizes are based on length, volume or area depending on the item being tested and local practice. The recommendations in Table RCC-4 apply to typical medium-sized projects. Consider varying the lot sizes or including sublots depending on the size of the project. Sublots (4 sublots per lot) may be beneficial when larger projects are being constructed. Typical lots sizes are:

- Length based lots range from 250 to 1000 ft (75 to 300 m); typically 500 ft (150 m);
- Area based lots range from 500 to 1500 yd<sup>2</sup> (420 to 1250 m<sup>2</sup>); typically 1000 yd<sup>2</sup> (850 m<sup>2</sup>);
- Volume based lots range from 100 to 500 yd<sup>3</sup> (75 to 380 m<sup>3</sup>); typically 300 yd<sup>3</sup> (850 m<sup>3</sup>);

<sup>13</sup> **Note to specification writer** – In Canada use CSA A23.2-12C for ASTM C31 and C39; CSA A23.2-14C for ASTM C42.

<sup>14</sup> **Note to specification writer** – For density testing, it is critical in RCC to use the direct transmission test method (with a probe) and not the backscatter test method. The critical density location for RCC is at the bottom of the RCC layer and only the direct transmission test method can assess the density at this location.

<sup>15</sup> **Note to specification writer** – Other specifications may refer to the Maximum Wet Density (MWD) to calculate the percent compaction achieved in the field. However, in practice the Reference Wet Density is preferred. For most RCC mixtures, the MWD occurs at the optimum moisture content (OMC) plus 1 to 3 percentage points. However, if an RCC mix is placed at a moisture content more than 1 to 1.5 percent above the OMC, it can be too wet, not properly support vibratory rollers, and not reach its strength potential. The formula to calculate the Reference Wet Density is defined in Terminology (page 5).

<sup>16</sup> **Note to specification writer** – While ASTM C1040 requires edge testing at 9 in. (225 mm) from the edge, ACPA recommends testing no closer than 12 in. (300 mm) so the testing does not damage the edge. For confined edges, testing can be done as close as 6 in. (150 mm).

<sup>17</sup> **Note to specification writer** – ACPA suggests making three cylinders for each lot or subplot, and using at least two for strength acceptance. Each cylinder should be visually observed for uniformity, with special attention to paste formation as explained in ASTM C1435. A testing technician may also need to roughen the surface between lifts to mimic bond where two lifts are made. To make sure cylinders are square it is important that they are capped properly.

<sup>18</sup> **Note to specification writer** – The owner may allow for modification to ASTM C1435 to allow five-lift molding. Based on field experience, it has been suggested that this better represents field compaction.

<sup>19</sup> **Note to specification writer** – In addition to determining thickness, the cores should be visually inspected to ensure that compaction at the bottom of the lift is obtained. If significant honeycombing or other signs of lower density are evident, check the cores for strength. On RCC projects with multiple lifts, these cores may also be used to ensure that the 2-lifts are bonded together.

## 4.0 RCC Mixture Design

**RCC-4.01 Mixture Design and Submittal.**<sup>20</sup> Proportion one or more mixtures complying with requirements in Sections RCC-2.02 and RCC-2.03. Submit certified test data for each proposed mixture in accordance with the quality management plan from the declared independent testing laboratory. Do not submit mix designs unless they meet the requirements outlined in Sections RCC-4.02 to RCC-4.04.

Include the following information for each mix design: 1) manufacturer certifications of material compliance with requirements listed in Table RCC-1; 2) quantity and gradation of each aggregate, as well as combined gradation; 3) quantity and types of each cementitious material; 4) type(s) of chemical admixtures and range of dosages; 5) optimum moisture content and reference wet density; and 6) strength results.<sup>21</sup>

**RCC-4.02 Cementitious Materials Content.**<sup>22</sup> Report the portland cement content in pounds per cubic yard (kilograms per cubic meter) as part of the mixture design. Replacing portland cement with supplementary cementitious materials (SCMs) is allowable to a maximum of 50% of the portland cement with ground granulated blast furnace slag or 25% of the portland cement with fly ash, or a combination of both, with fly ash not exceeding 25%.

**RCC-4.03 Minimum Compressive Strength.** The proposed laboratory mix design(s) shall meet the following minimum compressive strength (tested according to ASTM C39) based on test results of cylinders prepared according to ASTM C1435<sup>23</sup>:

- 4000 psi (28 MPa) at 28 days for RCC mixtures in areas without freeze-thaw conditions.
- 4500 psi (31 MPa) at 28 days for RCC mixtures in areas exposed to freeze-thaw conditions.<sup>24</sup>

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<sup>20</sup> **Note to specification writer** – While the mix design is an extremely important element of any RCC (or concrete) pavement specification, it is important to recognize laboratory mix designs are a “starting point.” As field conditions change, the contractor will need to make adjustments to materials proportions and admixture dosages in order to maintain a mixture that “will work in the field” for the given conditions.

<sup>21</sup> **Note to specification writer** – The RCC specified strength requirement must tie back into the strength used in the pavement design. Most design procedures are based on the “average in-field strength value” and incorporate design reliability to statistically account for the variability of strength and other design factors. As such, the strength you specify should match the “average in-field value” used in design and not an arbitrary value or a value lower than this figure. Note: 4000 psi (28 MPa) is a typical average compressive strength requirement that will meet a design assumption of 580 psi (4.0 MPa) flexural strength.

<sup>22</sup> **Note to specification writer** – This guideline leaves the cementitious materials content determination up to the contractor and material supplier for approval by the owner or Engineer. An RCC mixture must meet the quality parameters required in Table RCC-4 and the project needs (e.g. an intermodal facility versus a street). For RCC mix design, the minimum cementitious materials content is dependent on the strength and surface abrasion / scaling resistance requirements, and is affected by the quality and characteristics of available aggregates. While durable surfaces can be obtained with a cementitious materials content less than 400 lb/yd<sup>3</sup> (237 kg/m<sup>3</sup>), this is often considered a minimum quantity of cement to ensure the surface layer meets strength and resists abrasion, wear, and freeze/thaw durability.

<sup>23</sup> **Note to specification writer** – In Canada use CSA A23.2-12C.

<sup>24</sup> **Note to specification writer** – In Canada, the CSA A23.1-09 class of exposure C-2 in Table 1 governs, with minimum 32 MPa at 28-days and maximum water to cementing material ratio of 0.45. There are also air entraining and curing mandatory requirements, please consult Table 2 in the reference standard.

**RCC-4.04 Alternative or Additional Strength Requirements.** As an option, use alternative or additional strength testing to Section RCC-4.03 with the Engineer's approval.

## 5.0 Equipment

**RCC-5.01 General.** Furnish equipment matching those listed in the quality control plan and approved by the Engineer before starting work.

**RCC-5.02 Mixing Plant.** Obtain the Engineer's approval of the mixing plant before starting RCC production. Use a mixing plant capable of producing a homogeneous RCC mixture in the proportions<sup>25</sup> defined in the approved mixture design and conforming to the tolerances specified in ASTM C94<sup>26</sup> for batch mixing plants or ASTM C685<sup>27</sup> for continuous mixing plants.

Use a plant with production capacity sufficient to produce a uniform RCC mixture at a rate compatible with the placement operation. The Engineer can halt operations if the plant is unable to produce the RCC mixture sufficiently in quality or quantity, until operations are adjusted or a plant meeting all requirements is obtained.<sup>28</sup>

**5.02.1 Pugmill Plant.** Pugmill plants shall be central plant type with a twin-shaft pugmill mixer, capable of continuous mixing.

**5.02.1.a: Synchronized metering devices and feeders.** Provide synchronized metering devices and feeders to dispense the correct proportions of aggregate,

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<sup>25</sup> **Commentary** – All mixing plants require aggregate bins with feed rate controls either by a variable speed belt, or an operable gate calibrated to accurately deliver any specified quantity of material. If two or more aggregate size stockpile sources are used, the feed rate from each bin must be readily adjustable to change aggregate proportions, when required. Feed rate controls must maintain the established proportions of aggregate from each bin to provide the approved gradation.

<sup>26</sup> **Note to specification writer** – As an alternative to ASTM C94, select AASHTO M157 or CSA A23.2, whichever best represents the owner. Substitute in all sections of the project specification.

<sup>27</sup> **Note to specification writer** – As an alternative to ASTM C685, select AASHTO M241 or CSA A23.1, whichever best represents the owner. Substitute in all sections of the project specification.

<sup>28</sup> **Commentary** – A key requirement for the mixing plant is that its production rate meets the requirements of the paving operations, in order to maintain uninterrupted placement. The test strip (Section RCC-6.02) allows the Engineer to judge the adequacy of the mixing operation and uniformity of the material it produces.

For high-production projects, consider requiring the plant to have a minimum manufacturer's rated capacity of 200 tons (181 metric tons) per hour to maintain uninterrupted placement. Most concrete plants (pugmill, continuous, or portable horizontal shaft batch mixers) can be configured to meet this desired production rate. Tilt-drum mixers may be able to produce similar volumes. However, it is important to understand that tilt-drum mixers should be operated at less than full drum capacity and with longer mixing cycles to achieve quality mixing of the harsher, drier nature of RCC mixtures compared to conventional concrete mixtures. (Contractors report good results when using 50-75% of the drum capacity and mix cycle times of 90-120 seconds for these types of plants.) The contractor's quality management plan should indicate the target volume and mixing cycle time, which will provide an indication that the contractor is aware of what is necessary.

For projects with 50 tons per hour (45 metric tons per hour) or less production capacity needed, alternates to pugmill, continuous, tilt-drum or portable horizontal shaft batch mixers may be proposed and evaluated at the test strip. If the contractor can demonstrate that the mixing plant can satisfy the project production rate and quality/uniformity in the entire test section, the Engineer may allow for its use.

cement, supplementary cementing materials, and water for continuous mixing within the tolerance requirements of ASTM C685 depending on plant type.

**5.02.1.b Surge Hopper.** Provide a surge or gob hopper attached to the final discharge belt to temporarily hold the mixed RCC, in order to minimize segregation when loading into haul trucks, and to allow the plant to operate continuously.

**5.02.2 Central Mix Batch Plant.** Central Mix Batch plants shall be Tilt Drum Rotary or Horizontal Shaft Mixers. Use a mixer capable of producing a homogeneous mixture, uniform in texture and meeting the requirements of ASTM C94. Equip the mixer with batching equipment to meet the following requirements:

**5.02.2.a Weigh Hoppers.** Provide sufficient capacity to hold at least 10 percent more cementitious material than required for one batch, and equipped with vibrators to operate automatically and continuously while being dumped.

**5.02.2.b Timing Device.** Provide an accurate measure and visible indication of mixing time after all the materials, including the water, enter the mixer.

**RCC-5.02.3 Alternate Mixing Equipment.** Obtain the Engineer's approval before using alternative mixing equipment, including portable pugmill mixers for dry batch plants conforming to ASTM C685, or truck mixers conforming to ASTM C94. Demonstrate that the mixing equipment has the ability to produce a consistent, well-blended, non-segregated, homogeneous RCC mixture in the proportions defined in the approved mixture design, and within the capacity and tolerance limits specified in Section 5.02.1 or Section 5.02.2, as appropriate. Demonstrate that the equipment meets hourly production rates proposed in the Quality Management Plan.

**5.02.4 Cementitious Material Storage Silos.** Provide separate and independent storage silos to store and supply portland cement, blended cement and individual supplementary cementitious materials. Label each silo clearly near the fill inlet to prevent loading errors.

**RCC-5.04 Paving Machine.** Obtain the Engineer's approval of the paving equipment before starting RCC placement. Furnish a paving machine equipped with a high density<sup>29</sup> screed capable of placing the RCC material to a minimum of 90% of the reference wet density in accordance with ASTM D1557 or equivalent test method, prior to any

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<sup>29</sup> **Note to specification writer** – RCC contractors report the best results using compaction and high-compaction screeds, also referred to as high-density screeds. Compaction screeds are equipped with a single tamper bar and vibration, whereas high-compaction screeds are equipped with dual tamper bars, a tamper bar and pressure bar, or a tamper bar and dual pressure bars. Both compaction and high-compaction paving equipment provide better compaction through the paving machine and require less post placement rolling to achieve the required wet density than conventional asphalt paving machines equipped with only a vibratory screed. Paving machines equipped with high-compaction screeds often achieve densities greater than 90% before roller compaction. This is particularly important for pavement placed to a tighter smoothness requirement or in thicker lifts, as paving pass elevation and thickness variability are controlled better with equipment capable of placing RCC to a higher initial density. The higher initial density reduces the necessary compression of the material (roll down) with compaction equipment.

In general, high-compaction screeds are better suited for thicker heavy-duty applications, and where surface elevation requirements may be stricter. Likewise, compaction screeds are subject to more surface elevation variation from additional roll down for compaction, but are more economical and may be capable for some single lane wide placement or light pavement applications.



additional compaction.<sup>30</sup> Ensure that the paver is of suitable weight and stability, equipped to spread, compact, and place the RCC mixture to the required thickness, cross slope, edge and surface texture. Do not use graders, bulldozers, or any equipment that does not provide compaction during paving, except as required for areas inaccessible to a paving machine or requiring odd-shapes.

**RCC-5.05 Compaction Equipment.** Furnish self-propelled vibratory dual steel drum and/or pneumatic rollers capable of providing primary and final compaction efforts necessary to meet the in-place, wet-density requirements of Table RCC-4, as appropriate, and in a manner comparable to the test strip demonstration.<sup>31</sup> Furnish each drum on steel drum vibratory rollers with a properly operating scraper and brush. Only operate steel drum vibratory rollers in static mode for final compaction. Never operate a roller or paver in vibratory mode when the equipment is not in motion. Furnish walk-behind vibratory rollers or plate tampers only for compacting areas inaccessible to larger rollers.

**RCC-5.06 Haul Trucks.** Furnish trucks for transporting the RCC material from the plant to the paver. On long hauls, equip open-bed haul trucks with retractable protective covers to protect the RCC material from rain, evaporation, heat and other detrimental weather conditions. Provide a sufficient number of trucks to ensure adequate and continuous supply of RCC material to the paver.

**RCC-5.07 Water Truck.** Furnish a water truck, or other similar equipment, on-site and available for use throughout the paving and curing process. Equip the truck or device with a spray bar capable of evenly applying a fine spray of water to the RCC, subgrade or subbase surface without damage.

**RCC-5.08 Concrete Saws.**<sup>32</sup> Furnish concrete saws that are capable of sawing new RCC for crack control with minimal raveling and to the depth shown on the plans. Equip all saws with blade guards and guides or devices to control alignment and depth.

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<sup>30</sup> **Commentary** – The achievable density behind any type of paver depends upon the mixture. In some cases, even a seemingly good compactable mixture may come out the back of a high-density screed at less than 90% density, and require more compaction effort with rollers. RCC density, especially at the bottom of the RCC layer, is ultimately the key to good long-term pavement performance. It is important that contractors choose from among allowable methods carefully.

<sup>31</sup> **Commentary** – A vital aspect of RCC pavement placement is meeting the in-place wet density requirement. Contractors may approach this in a different ways, including using high-density screeds that may be capable of meeting the required density with little to no additional roller compaction necessary. Lift thickness is an important variable and contractors may use a steel-drum roller having a maximum static weight of 8 tons (7.3 metric tons) for RCC layers 6 in. (150 mm) thick or less, and 10 tons (9.1 metric tons) for thicker layers. For final compaction, rollers weighing from 2 to 8 tons (1.8 to 7.3 metric tons) are typical.

<sup>32</sup> **Note to specification writer** – It is a design option to include saw cut joints in RCC pavement. In cases where joints are required, it is advisable not to specify a specific type or style of saw for the project and to allow the contractor to choose the saws depending upon previous experiences. Providing the contractor this freedom ensures the highest degree of success in jointing the pavement. Also note that it is often necessary for the contractor to saw at night to prevent random cracking. The noise generated from sawing operations may exceed that allowable by local municipal noise-ordinances. Agencies and contractors should meet with law-enforcement agencies before starting a project to explain the necessity of night sawing and to receive special permission to violate a noise ordinance. To avoid late-night sawing a contractor may also choose to use an early-entry dry saw that permits joint sawing sooner than a wet-diamond saw. Saw cut depth also depends on the equipment, with early-entry saws requiring a shallower cut than conventional concrete saws.

## 6.0 Construction

**RCC-6.01 Proof Rolling.** Prior to placing RCC pavement, check for any soft or yielding subgrade or subbase areas by proof rolling with a loaded dump truck or pneumatic-tired roller over the entire area to be paved. Correct and make stable any soft or yielding subgrade areas prior to RCC layer construction.<sup>33</sup> Remove any unsuitable soil or material and replace with acceptable material.

**RCC-6.02 Test Section.**<sup>34</sup> Construct a <consider: 50 to 100-ft (15 to 30 m)<sup>35</sup>> long test section no less than 7-days prior to starting construction.<sup>36</sup> Construct the test section using the proposed mixture design, and with the materials and equipment listed in the quality management plan and approved by the Engineer. If the placement requires more than one pass of the paver, construct the test section a minimum of two paver widths wide. If the pavement placement requires more than one lift, construct the test section to the required number of lifts. Place the test section in a location approved by the Engineer. It is acceptable to place and leave the test section as part of the completed pavement if it complies with all acceptance testing criteria.

The Engineer shall evaluate the following criteria from the test section:

- Adequacy of mixing plant to meet productivity requirements and produce consistent material.
- Maximum density directly behind the paver prior to roller compaction.
- Suitability of the proposed lift thickness.

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<sup>33</sup> **Commentary** – Proper preparation of the subgrade and subbase will ensure the foundation under the RCC and areas supporting the paving equipment will not contribute to deficient pavement density, thickness or excessive yield losses. The subgrade is typically compacted at 1 to 3% above the optimum moisture and to a minimum of 95% of the maximum dry density in accordance ASTM D698 or AASHTO T99. Aggregate subbases are typically compacted at a minimum of 95% of the maximum dry density in accordance with ASTM D1557 or AASHTO T 180. Provisions for the subgrade density and surface tolerance are considered to be specified elsewhere – see Section 1.01 and Note 1.

<sup>34</sup> **Commentary** – The Test Section is one of the most critical steps in the path to a quality project. This is where laboratory experience and assumptions meet the reality of the specification, contractor personnel, equipment, placement conditions and RCC mixture production. The test section should be completed after the RCC contractor has declared that the mix, machines and people have made the adjustments necessary to demonstrate the final product. It is important that the Contractor be allowed to make mix adjustments and machine adjustments while the test section is placed/evaluated. The test section should include demonstration of all of the joints that are expected to be placed on the work, as well as full execution the of the QC/QA plan. When there are multiple lifts, the test section should demonstrate the contractor can meet all time requirements and/or limits to the pre-paving set-up to efficiently and effectively move the paver onto the pavement for the second lift.

<sup>35</sup> **Note to specification writer** – The test section length of 50 to 100-ft (15 to 30 m) is provided as a typical length. The length should be based on the size and complexity of the project (larger, more complex projects may require longer test sections and smaller, less complicated projects smaller test sections). However, no matter the size, it is important to define a minimum and maximum length in the bid documents so that the contractor can work the test section into his bid costs. A minimum length protects the owner by ensuring the contractor can properly place the RCC. The maximum length protects the contractor from having to construct a test section beyond the length needed to demonstrate the construction.

<sup>36</sup> **Note to specification writer** – The minimum of 7 days required before production paving allows for strength evaluation using cores to evaluate in-place strength results. These test section results allow a correlation to be made between fabricated cylinders and extracted cores. The correlation facilitates using cylinders as the primary mode of field evaluation once production paving begins. Cores may also be used for referee testing. (Note: Some contractors elect to use extracted beams for in-place correlation.)

- Sequence of primary/ secondary roller passes (with and without vibration).
- Maximum density following roller compaction.
- Texture and surface finish acceptability.
- Integrity of both fresh and cold joints (vertical and horizontal).
- RCC compressive strength based on cylinders and extracted cores tested at 7 days.<sup>37</sup>

If the test section does not meet acceptance requirements, remove and reconstruct a new test section with corrected procedures at no additional cost to the Owner.

**RCC-6.03 Producing RCC.** Conform to applicable sections of ASTM C94 and ASTM C685, and the following requirements.

**6.03.1 Storing and Handling Material General.** Store and handle all material in a manner that prevents cross contamination. Do not use any material that has been stored for a period exceeding the manufacturer’s recommended shelf life. Do not use cement or supplementary cementitious materials containing evidence of moisture contamination. Where recommended by the manufacturer, agitate chemical admixtures to ensure consistency during use.

**6.03.2 Storing and Handling Aggregate.** Place aggregate stockpiles on paved pads or 12 inch (300 mm) sacrificial layers of the aggregate to prevent accidental contamination by stockpile loader operators. Store and handle aggregate in a manner that ensures reasonably uniform moisture content at the time of batching.

**6.03.3 Mixing RCC.** Mix the RCC material following the approved mixture proportions and within the tolerances in ASTM C94 for central mixed concrete and ASTM C685 for volumetric batching and continuous mixed concrete. For a new or additional mixture, submit a revised mixture design for approval by the Engineer before making any changes in supply sources or character of the materials. Follow the guidelines of 4.0 RCC Mixture design. Do not use unapproved RCC mixtures.

**6.03.4 Plant Calibration.** Prior to RCC material production, conduct a complete and comprehensive calibration of the plant in accordance with the manufacturer’s recommended practice. Provide all scales, containers, and other items necessary to complete the calibration. Calibrate the plant at the times specified in Table RCC-3.

To maintain accuracy, keep the sides of the mixer and mixer blades free of hardened RCC material or other buildups. Routinely check mixer blades for wear and replace if wear is sufficient to cause inadequate mixing per manufacturer’s recommendations.

**6.03.5 Charging the Mixer.** For plants conforming to ASTM C94 ensure that the volume of mixed material per batch does not exceed the manufacturer’s rated capacity of the mixer.<sup>38</sup> For batch mixers, discharge all material in the mixing chamber before recharging.

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<sup>37</sup> **Note to specification writer** – For compressive strength testing, it is recommended that cores be taken and broken at 7 days, and then related to the 28-day strength per ASTM C-42 modified to allow for early testing. The goal is for core strengths to reasonably match the strength of lab specimens at the same times.

<sup>38</sup> **Commentary** – Because of the dry and stiff consistency of RCC, contractors report the optimal batch volume of mixed material, especially for drum and horizontal shaft mixers, is typically about 50% to 75% of the manufacture’s rated capacity of the mixer for conventional concrete, dependent the specific mixing equipment being used.

**6.03.6 Mixing Time.** Mix the materials a sufficient length of time in the mixer to ensure thorough and complete blending of all ingredients. For plants conforming to ASTM C94, mix each batch for the minimum time recommended by the plant's manufacturer.<sup>39</sup>

**6.03.7 Daily Reports.** Produce and maintain records of production and quantities of materials used in the plant. Supply these reports to the Engineer daily.

**RCC-6.04 Transporting RCC.** Transport the RCC material from the plant to the areas to be paved in dump trucks equipped with retractable protective covers for protection from rain or excessive evaporation, as necessary for the weather conditions. Do not exceed a <insert time<sup>40</sup>> minute haul time. The Engineer may increase or decrease the time requirement depending upon the ambient conditions and approved use of set retarding admixtures in the mixture. To minimize segregation during loading, load trucks uniformly across the entire bed of the truck.<sup>41</sup> Ensure that the trucks are dumped clean with no buildup of RCC material in the corners.

**RCC-6.05 Placing RCC.** Deposit the RCC material directly into the hopper of the paver or into a secondary material distribution system that deposits the material into the paver hopper. Time the delivery and placement so that RCC material is spread with minimum stops and compacted within the time limits specified in Section 6.09.1. Place the RCC mixture without segregation.<sup>42</sup>

When using dual lift construction, feed the RCC material to the paver by an approved material transfer device that possesses the following characteristics:

- The ability to feed the paver at a rate which allows for continuous forward motion of the paving machine.
- The ability to feed the paving machine from an offset position which is outside of the initial lift of RCC pavement.

If RCC material is left in the paving machine past the delivery and placement time limits specified in Section 6.09.1, pull the paving machine off the placement and construct a cold joint in accordance with Section 6.10.2. The Engineer may increase

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<sup>39</sup> **Note to specification writer** – Mixing time requirements vary depending upon batch plant mixer design and era of manufacturing. This guideline requires the contractor to report the mixing time proposed as part of the quality management plan. Additionally, you may consult the plant manufacturer to verify the time appropriate for the plant provided by the contractor or set the mixing time requirement based on a performance test (see ASTM C94) performed by the contractor during the test strip operation. (Note: The mixing time begins after all cement and aggregate enters the drum and ends when the discharge chute opens. Transfer time in multiple-drum mixers is included in the mixing time.)

<sup>40</sup> **Note to specification writer** – The total maximum time allowed between the beginning of the mixing operation and final compaction of the RCC mixture is 60 minutes (see Section 6.09.1). The specification writer should adjust the maximum delivery time based on the project specifics to ensure that mixing, delivery, placement and compaction all occur within this 60 minute window.

<sup>41</sup> **Commentary** – Aggregate segregation can occur if haul trucks are loaded in a single pile at the center of the truck bed. To minimize segregation, trucks should be loaded in multiple piles or have the truck move slowly forward while loading from the front to the back. A gob or surge hopper at the end of the loading belt will also prevent aggregate segregation in truck beds.

<sup>42</sup> **Commentary** – For large volume projects, and/or projects to serve high-speed traffic [considered 35 mph (55 kph) or more], the Contractor should consider a material transfer device along with a surge hopper on the paver to allow the paver to move forward with minimal stopping. This will provide better results for both consistency and surface smoothness.

or decrease the placement time requirement depending upon the ambient conditions and approved use of set retarding admixtures in the mixture.

**RCC-6.06 Subbase Condition for Placement.** Do not place RCC material on frozen ground or in standing water. Prior to proof rolling the grade and placing RCC material, ensure that the surface of the subgrade/subbase is clean and free of foreign material, ponded water, and frost. Ensure that the subgrade/subbase is uniformly moist at the time of RCC material placement. If moistening certain areas is necessary, ensure that the method of sprinkling will not form mud or pools of free standing water.

**RCC-6.07 Weather Conditions.**

**6.07.1 Cold Weather Precautions.** Stop placement operations when the air temperature falls below 40°F (5°C) and is declining. Start operations only if the air temperature is at least 35°F (2°C) and is rising.

If the air temperature is expected to fall below 40°F (5°C) at some time during placement operations, apply the cold weather procedures outlined in the quality management plan and approved by the Engineer. Provide a sufficient supply of protective material on site. RCC paved during cold weather is subject to the quality requirements outlined in Sections RCC-4.01 to RCC-4.04 and Table RCC-4.

**6.07.2 Hot Weather Precautions.** Take special precautions to minimize moisture loss due to evaporation during periods of hot weather [more than 90°F (32°C)]<sup>43</sup> or windy conditions, including but not limited to the following options: cooling of aggregate stockpiles by shading or the use of a fine misting, covering haul truck beds, cooling RCC mix water, and decreasing the allowable time between mixing and final compaction. Keep the surface of the newly placed RCC layer continuously moist with mist sprayers until applying curing compound.

**6.07.3 Rain Limitations.** Stop placement operations when it is raining hard enough to be detrimental to the finished product. Placement is acceptable during light rain or mist provided the surface of the RCC layer does not erode, scab or damage. Cover dump truck beds during these periods to protect material during transport.

**RCC-6.08 Paving.** Only place RCC material with equipment listed in the quality management plan and meeting the requirements of Section RCC-5.04, including subsections.

**6.08.1 Lift Thickness Range.** Place RCC in lifts generally between 4 in. (100 mm) and 10 in. (250 mm) thick. The Engineer may approve placing lifts at thicknesses at 10 in. (250 mm) or greater with successful demonstration that the proposed method meets all requirements of Table RCC-4, Sections 5.04, 6.02 and 7.04, including ASTM C 1040 density testing using direct transmission test method (with a probe) at multiple locations throughout the entire lift thickness range.

**6.08.2 Adjacent Lane Placement.** Place adjacent paving lanes within 60 minutes. Keep the fresh edge<sup>44</sup> (fresh vertical joint) from drying out until the adjacent lane is placed either by increasing productivity with tandem paving, spraying the joint

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<sup>43</sup> **Note to Specification writer** – In Canada use a hot weather threshold of 27°C per CSA A23.1.

<sup>44</sup> **Commentary** – A joint is considered fresh if: (1) the RCC surface remains moist (note: changing color of coarse aggregates is a good indication that the RCC surface is drying); and (2) it is not exposed for more than 60 minutes.

surface with a light water mist, applying wet burlap cover, or by using a set-retarding admixture in the RCC mixture with proper approval.

If more than 60 minutes elapses between placements of adjacent lanes, consider the fresh vertical joint a cold vertical joint and prepare it in accordance with Section 6.10.2. The Engineer may increase or decrease the 60 minute adjacent lane placement requirement depending upon the ambient conditions and approved use of set retarding admixtures in the mixture.

**6.08.3 Multiple Lift Placement.** For multiple lift placements, compact the bottom lift to the specified minimum wet density before placing the next lift. Place and compact the top lift within 60 minutes of the completion of the bottom lift. Keep the surface of the bottom lift clean of debris, and prevent it from drying prior to placing the subsequent lift by increasing productivity with tandem paving, spraying the bottom lift surface with a light water mist or by using a set-retarding admixture in the RCC mixture with proper approval.

If more than 60 minutes elapses between lift placements, consider the interface between the top and bottom lifts as a cold joint and prepare the bottom lift surface in accordance with Section 6.10.4. The Engineer may increase or decrease the 60 minute lift placement requirement depending upon the ambient conditions and approved use of set retarding admixtures in the mixture.

**6.08.4 Hand Spreading.** Do not broadcast or spread RCC material across areas being compacted. Hand repair of small, isolated surface locations is permissible only immediately behind the paver and before any roller compaction operations begin in the area. Use only fresh RCC material from in front of the paver as repair material.<sup>45</sup>

**RCC-6.09 Compaction.** Only compact RCC material with approved equipment listed in the quality management plan, and that meets the requirements of Section RCC-5.05, including subsections.

**6.09.1 Compaction Timing.** Begin compaction as soon as practical after paver placement and complete all compaction operations within 60 minutes of the RCC material being mixed. The Engineer may increase or decrease this time depending on use of set retarding admixtures or the ambient conditions of temperature, wind, and humidity. Do not delay rolling operations from the timing approved in the quality management plan and validated in test strip construction unless approved by the Engineer.

**6.09.2 Compaction Process.** Apply the sequence and number of passes by vibratory and non-vibratory rolling to obtain the specified density proposed in the quality management plan and verified on the test section. Do not operate rollers in the vibratory mode while stopped. Use steel drum rollers in static mode and/or rubber-tire rollers for final compaction.

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<sup>45</sup> **Commentary** – Hand spreading of thin layers of RCC to correct minor depressions or low spots are likely to peel off. For isolated areas such as rock pockets, depression, etc. that need to be filled, experience indicates it is preferable for the contractor to dig out and remove the material, roughen the surface, and replace with fresh material. Such operations must occur between the paver and rolling operations and must be done before any rolling occurs.

**6.09.3 Compacting Longitudinal and Transverse Joints.** Do not operate a roller within 2 ft (0.6 m) of the edge of a freshly placed lane until the adjacent lane is placed. Then, roll both edges of the two lanes simultaneously within the allowable time. If a cold joint is planned, roll the complete lane and follow the cold joint requirements specified in Section 6.10.2. For freshly placed RCC next to an existing cold joint, roll the complete lane, taking extreme care not to bridge the roller drum between the new unconsolidated fresh material and a previous cold joint edge. Such bridging of roller drum over cold joint edges, especially in vibratory mode, can significantly degrade the cold joint edge.<sup>46</sup>

**6.09.4 Compacting Areas Inaccessible to Larger Rollers.** Compact any areas inaccessible to a large roller using a small drum roller, a walk-behind vibratory roller or a plate tamper. Cast-in-place, conventional concrete meeting the same strength requirements in Table RCC-4 may be used in these areas as a replacement for RCC with prior approval of the Engineer.

**6.09.5 Density Requirements.** Perform in-place density tests in accordance with the requirements of Table RCC-4.

#### **RCC-6.10 Joints.<sup>47</sup>**

**6.10.1 Fresh Vertical Joints.** A vertical joint is considered fresh only when a subsequent RCC lane is placed within 60 minutes or the time limit approved by the Engineer. See Section 6.08.2 for allowable procedures to keep a fresh edge from drying out. If more than 60 minutes or the time limit approved by the Engineer elapses between placements of adjacent lanes, consider the fresh vertical joint a cold vertical joint and prepare it in accordance with Section 6.10.2.

**6.10.2 Cold Vertical Joints.** Consider any planned or unplanned vertical construction joint that does not qualify as fresh vertical joint as a cold vertical joint. Prior to placing fresh RCC material against a compacted cold vertical joint, thoroughly clean the cold vertical joint of loose or foreign material. Wet the cold vertical joint face and maintain it in a moist condition immediately prior to placement of the new lane.

Remove a minimum of 6 in. (150 mm) full-depth from the exposed longitudinal edge of any cold vertical joint that does not meet the minimum joint density requirements in Table RCC-4. Do not perform this operation any sooner than 2 hours after final compaction. Demonstrate to the Engineer that saw cutting will not cause significant edge raveling and remove all slurry and excess material from the cutting operation.

The Engineer may approve the use of an edge shoe for vertical cold joint construction with successful demonstration that the proposed alternate meets the minimum joint density requirements in Table RCC-4, and the edge shoe produces a face with no more than an angle of 15 degrees from vertical.

**6.10.3 Horizontal Joints.** A horizontal joint is considered fresh only when a subsequent RCC lift is placed within 60 minutes or the time limit approved by the

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<sup>46</sup> **Commentary** – The primary requirement is that rolling operations do not roll over a “free” edge. This will cause the RCC to be “pushed out” resulting in inadequate compaction, low density and poor smoothness.

<sup>47</sup> **Commentary** – Section 7 of the “Guide for Roller-Compacted Concrete Pavements” NCPTC Document SN298 (Reference 2) provides detailed information on joint construction.

Engineer.<sup>48</sup> See Section 6.08.3 for allowable procedures to keep the surface of the bottom lift continuously moist and clean of all loose material prior to placing the subsequent lift.<sup>49, 50</sup>

If more than 60 minutes elapses between lift placements, consider the interface between the top and bottom lifts as a cold horizontal joint and prepare the bottom lift surface in the manner demonstrated and approved on the test section to ensure that bond occurs between layers. The Engineer may increase or decrease the 60 minute lift placement requirement depending upon the ambient conditions and approved use of set retarding admixtures in the mixture.

**6.10.4 Crack Control Joints.**<sup>51</sup> If required on the plans, construct transverse contraction or crack control joints in the RCC layer by sawing with approved equipment listed in the quality management plan, and that meets the requirements of Section RCC-5.08. Saw crack control joints to the interval, depth and width specified on the plans. Extend all crack control joints the entire width of paving. When sawing crack control joints, begin as soon as the RCC cuts without excessive raveling along the saw cut and finish before conditions induce uncontrolled cracking, regardless of the time or weather.

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<sup>48</sup> **Note to specification writer** – For fresh joints, while the specification allows for 60 minutes, experience has shown that the sooner the second layer is placed, the easier it is to achieve bond. As such, most contractors typically try to place the second layer within 30 minutes in order to maximize the opportunity to achieve good bond strength.

<sup>49</sup> **Note to specification writer** – This guideline allows the contractor to propose a method for treating cold horizontal joints as part of the quality management plan based on their experience and the availability of equipment. Past industry experience with cold horizontal joints is that bonding cannot be obtained reliably with just cleaning and moistening the surface of the bottom lift. The horizontal surface of the bottom lift must be cleaned with air or water jets to remove debris and dust before the top lift is placed. Full bond between the layers may be achieved by applying a thin layer of high-slump mortar or grout immediately prior to placement of the upper lift.

DO NOT require wax-based or other curing compounds on bottom lifts, which may impede bonding of subsequent lifts. When cleaning a lower lift surface, care must be taken to expose the fine aggregate enough to promote bonding, without undercutting the coarse aggregate. Acceptable cleaning can include water blasting, blowing with compressed air, or a combination of water and compressed air. The type of equipment that will be most effective will depend on the strength of the RCC at the time of cleaning.

<sup>50</sup> **Commentary** – The key to fresh and cold horizontal joints is obtaining bond between the two layers. However, it is important to note that because dual lift pavements are typically built in two lifts of equal thicknesses, shear stresses at the interface between the lifts are minimal, as this is the neutral axis under load. Bond is determined by coring the section at 7 days or later (if the core is intact with normal handling at extraction, the layers are determined to be bonded). It is important that the cores be taken at 7 days or later so that RCC has time to cure. Bond strength develops as the RCC hydrates. If cores are taken too soon, it is likely the bond strength will not be sufficient to even withstand the coring process. It is also important that a 4-inch (100 mm) diameter or larger core be used evaluate bond because smaller cores create a greater “twist” (shear) on the core during the coring operation, which can erroneously break the bond. Similarly, it is imperative that the core drill be in alignment and anchored properly to prevent excessive vibration that can also break the core at the bond line.

<sup>51</sup> **Commentary** – Conventional saws or early entry dry saws both work for RCC pavement crack control. It is recommended that the owner/agency not direct the contractor exactly when to saw or direct what equipment to use. The sawing operation should not cause raveling, tearing or chipping of the joint. If this occurs the sawing is too early or the blade is not matched properly to the RCC material. With conventional saws, cutting should typically start within 4 to 6 hours and no later than 12 hours after RCC layer construction. A cut depth of 1/4 the depth of the RCC pavement is typical, although deeper cuts to 1/3 the depth offers improved crack control potential. Crack control joints are typically spaced at intervals equal to 36 times the nominal RCC layer thickness; if random cracking occurs, a closer interval of 24 times the thickness may be required. Crack control joints are typically not sealed.



**6.10.5 Isolation Joints.** Line the perimeter of fixed structures such as building foundation slabs, manholes, valves, trench drains, and concrete curbs and gutters with strips of fiberboard or other approved isolation joint material, as noted in the plan details, prior to paving.

**6.10.6 Expansion Joints.** Install expansion joints to the details, dimensions and locations shown on the Plans. If the plans do not include details and conditions warrant expansion joints, propose a plan and install expansion joints in the pavement, with approval of the Engineer. Include width, filler, sealing material, location and/or spacing recommendations in the expansion joint plan, considering thermal effects, regional climatic conditions, RCC coefficient of thermal expansion and expected daily temperature ranges at the time of placement.

**RCC-6.11 Curing.** Immediately after final rolling and compaction tests, keep the surface of the RCC layer continuously moist for a minimum of five days or until an approved curing method outlined in the quality management plan is applied.

**6.11.1 Water Cure.** Apply water cure using water trucks equipped with misting spray nozzles, soaking hoses, sprinkler system or other means that will ensure a uniform moist condition to the RCC layer surface without damage. Apply misting spray in a manner that will not erode or damage the surface of the finished RCC layer.

**6.11.2 Curing Compound.** Use a concrete curing compound conforming to Table RCC-1 requirements. Apply the curing compound at a minimum application rate of 150 ft<sup>2</sup>/gal (3.7 m<sup>2</sup>/liter)<sup>52</sup> on the surface and edges of the RCC layer no later than one hour after completion of finishing operations.<sup>53</sup>

**6.11.3 Sheet Materials.** Use sheet curing materials conforming to Table RCC-1 requirements. Ensure coverings are held securely in place and weighted to maintain a close contact with the RCC layer surface throughout the entire curing period. Overlap the edges of adjoining sheets and hold in place with sand bags, planking, or similar method, as approved by the Engineer.

**6.11.5 Opening to Traffic.** Protect the RCC layer from vehicular traffic during the early curing period until the surface can withstand turning movements without marring or displacing RCC surface aggregates. In addition, do not place vehicular traffic on the pavement until the RCC attains the minimum strength required for structural consideration per Table RCC 5. Non-truck mounted curing equipment or saw-cutting equipment, necessary for proper construction and to meet other provisions of this specification, are allowable using techniques to prevent marring or displacing RCC surface aggregates.<sup>54</sup>

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<sup>52</sup> **Note to specification writer** – In most cases, exposed RCC surfaces have a more open texture surface than conventional concrete pavements. Thus, RCC surfaces typically require a higher application rate of curing compound than is required for conventionally textured concrete pavements.

<sup>53</sup> **Commentary** – A white-pigmented compound helps to ensure consistent coverage. The appearance of the cure should be a uniform whitish color, without mottling or discoloration due to incomplete coverage.

<sup>54</sup> **Commentary** – There is no specific criteria regarding the strength necessary for an RCC surface to withstand marring from turning vehicles; it depends upon the combination of RCC strength, turning action and weight of the loading. Typically, this is reached within one day in warm weather [above 70°F (21°C)] and three to four days in cooler weather [40° to 70°F (4° to 21°C)]. RCC strength gain may be accelerated or delayed depending on the mixture, particularly when chemical admixtures or SCMs are used.

**Table RCC-5 – Minimum Opening Strength For Structural Adequacy**

| Slab Thickness              | Compressive Strength for Opening to Public Traffic |                     |
|-----------------------------|----------------------------------------------------|---------------------|
|                             | Autos                                              | Mixed Traffic       |
| ≤ 5 inches (125 mm)         | 1100 psi<br>(7.6 MPa)                              | 4000 psi (27.6 MPa) |
| 5 – 6 inches (125 – 150 mm) |                                                    | 3600 psi (24.8 MPa) |
| 6 – 7 inches (150 – 175 mm) |                                                    | 2500 psi (17.2 MPa) |
| 7 – 8 inches (175 – 200 mm) |                                                    | 2200 psi (15.2 MPa) |
| > 8 inches (200 mm)         |                                                    | 2000 psi (13.8 MPa) |

## 7.0 Acceptance Criteria

### RCC-7.01 Thickness Requirements.

**7.01.1 Thickness Verification by Cores.** Determine the pavement thickness from cores by average caliper measurements in accordance with ASTM C174.<sup>55</sup> Extract one core for each lot of RCC pavement per Table RCC-4. For pavement placement units consisting of less than one lot of RCC pavement, include the pavement with the previous or next placement unit.

**7.01.2 Thickness Verification by Non-Destructive Device.** The Engineer may approve a non-destructive method for thickness verification with successful demonstration that the proposed alternate is sufficiently accurate to satisfy the requirements of Table RCC-4.

**7.01.3 Defective Area Correction for Pavement Thickness.** The thickness after compaction shall be no less than 0.25 in. (6 mm) under the RCC thickness, as specified on the Plans or drawings. Full payment shall be made for pavement represented by verification tests meeting this requirement. Pavement that has been purposely warped to meet fixtures (manholes, drainage inlets, and catch basins), existing curb and gutter, or cross- and side-roads are exempt from thickness measurement.<sup>56</sup>

Pavement represented by any thickness verification test that is outside of the tolerance is subject to further evaluation. Take two additional tests, about 30 ft (10 m) on either side of the deficient test in the direction paving (within the same placement unit). The work is subject to full payment if the average thickness of the three tests is no less than the Plan thickness minus 0.125 in. (3 mm). Define the

<sup>55</sup> **Note to specification writer** – As an alternative use AASHTO T148.

<sup>56</sup> **Commentary** – See Note 1 for prepared roadbed-trimming tolerance reminder. The contractor needs some latitude regarding the pavement thickness tolerance given the subbase construction tolerance, which in some cases may be provided by a separate contractor. This is also important because measurement and payment for RCC is based on an area unit (square yards or square meters) and the Contractor must estimate yield loss to properly account for project site variations (See Section 8.0 for basis of measurement and payment). In selecting thickness testing locations, it is important to avoid getting too close to locations where it is known that the placement was constrained to meet a specific site requirement, such as drainage structures and existing pavements, aprons, etc.

limits of thickness deficiency through additional tests as needed. For areas defined by the limits of testing to be deficient, propose a solution (either removal and replacement, repair method or adjusted contract unit price) to the Engineer/Owner. The proposed solution shall provide an as-built condition structurally equivalent to or greater than the design, or compensate for reduced value through a unit price adjustment, to the approval of the Engineer and at no expense to the Owner.

## **RCC-7.02 Density Requirements.**

**7.02.1 In-Place Wet Mat Density Determination.** Determine the In-place Wet Mat Density on pavement at least 24 in. (610 mm) from any joint in accordance with ASTM C1040 direct transmission mode for each lot per Table RCC-4. For pavement placements of less than the size of one lot, include the pavement with the previous or next lot.

**7.02.2 In-Place Wet Joint Density Determination.** Determine the In-place Wet Joint Density on joints at distance 12 in. (305 mm) or greater from a free edge and 6 in. (150 mm) or greater from a confined edge accordance with ASTM C1040 direct transmission mode for each lot per Table RCC-4. For pavement placements of less than the size of one lot, include the pavement with the previous or next lot.

**7.02.3 Correction for Density.** For in-place wet mat and joint density, full payment shall be made for pavement based on the acceptance criteria in Table RCC-4. Lots that have a density measurement that is less than the required density requirement are subject to further evaluation. Take an additional test within a 5 to 8 ft (1.5 to 2.5 m) radius of the original test (within the same placement unit). If the additional test result is below the acceptance criteria in Table RCC-4, apply additional roller passes across the full lane width between the last testing location that produced an acceptable reading and the paver. If the additional rolling does not correct the problem, or causes the density to decrease, discontinue paving until corrections are made to assure the Engineer that the minimum density is achieved.

## **RCC-7.03 Strength Requirements.**

**7.03.1 Strength Determination.** Determine the compressive strength of cylinders based on the acceptance criteria in Table RCC-4. For pavement placements of less than the size of one lot, include the pavement with the previous or next lot.

**7.03.2 Remedial Action for Deficient Strength.** Full payment shall be made for cylinder tests if the average strength is equal to 100% of the specified strength in Sections RCC-4.03 and 4.04, with no single result below 90%.

Pavement lots that have an average strength less than the required strength in Sections RCC-4.03 and 4.04 are subject to further evaluation.<sup>57</sup> Extract three cores at

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<sup>57</sup> **Commentary** – While inadequate construction, materials, and/or compaction are among several of the reasons that the RCC strength may be below the specified strength, two other common reasons are that the test specimens are of suspect quality, fabrication, transport or curing; or the testing procedures or test machines are of suspect quality or calibration. Referee testing identifies whether low strength results are from poor testing practices.

random locations in the suspect area once the pavement is 28 days old. Remove, handle and test the compressive strength of the cores according to ASTM C42.<sup>58</sup>

Determine the average and standard deviation of the compressive strength of the three cores. If the average of the three cores exceeds 85% of the minimum specified compressive strength in Sections RCC-4.03 and 4.04, the RCC in the subplot is acceptable and is subject to full payment and acceptance. If the average strength of the three cores is less than 85% of the specified compressive strength in Sections RCC-4.03 and 4.04, the RCC is not acceptable and requires removal per Section 7.03.3

**7.03.3 Removal and Replacement.** Areas determined to have strength deficiencies that are not resolved through referee testing (Section 7.03.2) require removal and replacement without additional payment. After the referee period or at least seven days, remove the hardened RCC material by saw cutting the perimeter of the deficient area full depth. Repair the area using an air-entrained cast-in-place concrete meeting the strength requirements of Table RCC-3 or as directed by the Engineer. If the repair is prepared using conventional concrete, drill and grout dowels in the sawed, butt-faced transverse perimeter joints per table RCC-6.<sup>59</sup>

**Table RCC-6: Dowel Configuration for RCC Replacement with Conventional Concrete Pavement**

| Pavement Thickness<br>in. (mm) | Dowel Spacing<br>in. (mm) | Dowel Length<br>in. (mm) | Dowel Diameter<br>in. (mm) | Drilled Hole Diameter for |                   |
|--------------------------------|---------------------------|--------------------------|----------------------------|---------------------------|-------------------|
|                                |                           |                          |                            | Grout<br>in. (mm)         | Epoxy<br>in. (mm) |
| ≤ 7 (≤ 175)                    | None                      | –                        | –                          | –                         | –                 |
| 7 to 8 (175 to 200)            | 12 (350)                  | 12 (350)                 | 1.0 (25)                   | 1.2 (30)                  | 1.08 (27)         |
| 8 to 9.5 (200 to 240)          | 12 (350)                  | 12 (350)                 | 1.25 (32)                  | 1.45 (37)                 | 1.33 (34)         |
| 10+ (250+)                     | 12 (350)                  | 12 (350)                 | 1.5 (38)                   | 1.7 (43)                  | 1.58 (40)         |

**RCC-7.04 Surface Requirements.**

**7.04.1 Smoothness for RCC Pavements.**<sup>60</sup> Ensure that the finished surface, when tested with a 10-foot (3-m) straightedge, does not vary from the straightedge or template by more than 0.375 in. (9 mm) at any one point. In addition, the finished surface shall be within 0.625 in. (16 mm) of the specified finished grade. Pavement surfaces that have been purposely warped to meet fixtures (manholes, drainage inlets, and catch basins), existing curb and gutter, or cross- and side-roads are

<sup>58</sup> **Note to specification writer** – Consider also AASHTO T24 or CSA A23.2-14C., as appropriate for the Owner/Agency.

<sup>59</sup> **Commentary** – Dowels are required in a transverse repair joint because the saw cuts will leave a smooth butt-face joint with no means for load transfer. Providing mechanical load transfer is important for pavements serving high traffic volumes and/or heavier loads. Recommendations in Table RCC-6 are consistent with those in “Utility Cuts in Concrete Pavements,” ACPA Publication IS235P.

<sup>60</sup> **Note to specification writer** – This guideline provides acceptable surface smoothness for industrial pavement, parking area, and other low-speed traffic applications. For applications serving high-speed [35 mph (55 kph) or more] traffic, apply the local, state DOT or provincial ministry standard specifications for smoothness requirements. In such applications, consider requiring the placement operation to require use of a material transfer device during construction. For such applications, diamond grinding the surface may be required in order to meet smoothness requirements.

exempt from straightedge measurement. Correct surface irregularities outside of these tolerances per the requirements of Section 7.04.2.

**7.04.2 Correction for Smoothness:** Correct smoothness deficiencies from 7.04.1 using an approved grinding device without additional payment.<sup>61</sup> After correction, verify the corrective work by measuring the smoothness according to 7.04.1.

**7.04.3 Surface Texture<sup>62</sup>:** The final surface texture after rolling and curing shall be smooth and uniform over the entire area of pavement and shall reasonably match the surface condition of the test strip without rips, tears, cracking, segregation, rock pockets, or areas of loose aggregate.

**7.04.4 Correction for Surface Texture:** Correct surface texture deficiencies from Section 7.04.3 using an approved grinding device without additional payment, or removal and replacement per Section 7.03.3. With the Engineer's approval, defective surface areas may remain in place.

#### **RCC-7.05 Responsibility Prior to Acceptance of Work.**

**7.05.1 Maintenance and Care.** Maintain the RCC pavement in good condition until all work is completed and accepted.

**7.05.2 Snow and Ice Removal.** Do not apply any de-icing agents to the RCC surface for at least 60 days after placement.

## **8.0 Measurement and Payment**

**RCC-8.01 Measurement.** The quantity measured for payment under this specification shall be the number of square yards (square meters) of RCC pavement completed and accepted, as measured in place. RCC material placed outside of the area designated to be paved under the contract shall not be included in computing the number of square yards (square meters). Construction of joints and correction of defective placement is included in the total square yard (square meters) basis and no direct payment will be made for this work.

**RCC-8.02 Basis of Payment.** The area unit price shall provide compensation for furnishing all labor, equipment, and materials to place, finish, texture, cure and saw joints, in accordance with the Plans and these specifications, including compensation for furnishing all raw materials, and for proportioning, mixing and delivering concrete to the paving machine. All pavement accepted by the Engineer shall be paid at the contract price per unit for the pay items shown on the bid schedule or approved estimate, except for lots requiring price adjustments for deficiencies.

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<sup>61</sup> **Note to specification writer** – A grinding machine for bump grinding typically uses a cutting head with many diamond saw-blades. The grinding head produces 50-60 grooves/foot (164-197 grooves/meter) and can remove 0.125 to 0.75 in. (3-20 mm) from the pavement surface. Carbide milling or other impact equipment may not produce as smooth a surface and are not normally acceptable, although micro-milling machines may be acceptable for surface correction of some low-speed, industrial applications..

<sup>62</sup> **Note to specification writer** – It is important to recognize that RCC pavements will not have the surface texture of a conventional concrete pavement. Rather the RCC surface by nature has a more pitted, pockmarked or molted look and more closely resembles the surface of an asphalt pavement.