

ACI 327R-14

Guide to Roller-Compacted Concrete Pavements

Reported by ACI Committee 327



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Guide to Roller-Compacted Concrete Pavements

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Guide to Roller-Compacted Concrete Pavements

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This guide provides owner-agencies, contractors, materials suppliers, and others with a thorough introduction to roller-compacted concrete (RCC) and its many paving applications. This guide describes RCC and how it works as a paving material, how it compares to concrete pavement, its common uses and benefits, and potential limitations compared to other paving materials. Troubleshooting guidelines are provided, as well as detailed overviews of RCC properties and materials, mixture proportioning, structural design issues, production and construction considerations, and quality control.

Keywords: industrial pavement; inspection and testing; joints; pavement; pavement design; roller-compacted concrete (RCC); RCC mixture proportioning; RCC pavement construction; RCC production.

CONTENTS

CHAPTER 1—INTRODUCTION, p. 2

CHAPTER 2—NOTATION AND DEFINITIONS, p. 2

- 2.1—Notation, p. 2
- 2.2—Definitions, p. 2

CHAPTER 3—KEY ELEMENTS, p. 2

- 3.1—Performance comparison of RCC to conventional concrete pavement, p. 2
- 3.2—Materials and structural performance properties, p. 3

3.3—Performance differences between RCC and conventional concrete pavement, p. 4

3.4—Benefits of RCC, p. 5

3.5—Sustainability, p. 7

3.6—Potential limitations, p. 7

CHAPTER 4—COMMON USES, p. 7

4.1—Ports, intermodal facilities, and heavy industrial facilities, p. 7

4.2—Light industrial areas, p. 9

4.3—Airport service areas, p. 9

4.4—Arterial streets, p. 9

4.5—Local streets, p. 10

4.6—Widening and shoulders, p. 10

4.7—Multilayer pavement systems for high-speed uses, p. 11

4.8—Logging facilities, composting areas, and storage yards, p. 11

CHAPTER 5—PROPERTIES AND MATERIALS, p. 11

5.1—Roller-compacted concrete engineering properties, p. 11

5.2—RCC materials selection, p. 14

CHAPTER 6—MIXTURE PROPORTIONING, p. 16

6.1—Mixture proportioning methodologies, p. 16

6.2—Materials considerations in RCC mixture proportioning, p. 17

6.3—Methods for mixture proportioning, p. 18

CHAPTER 7—STRUCTURAL DESIGN, p. 20

7.1—Basis for design, p. 20

7.2—Subgrade, subbase, and base design, p. 21

7.3—Design procedures, p. 21

7.4—RCC-PAVE software (PCA procedure), p. 21

7.5—PCASE software (USACE procedure), p. 24

7.6—ACI design procedures, p. 25

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7.7—American Concrete Pavement Association Street-Pave design procedure, p. 27

7.8—Jointing, p. 27

CHAPTER 8—PRODUCTION, p. 31

8.1—Handling and storage, p. 32

8.2—Roller-compacted concrete mixing plants, p. 32

8.3—Batching and monitoring, p. 34

8.4—Production levels, p. 34

CHAPTER 9—CONSTRUCTION, p. 35

9.1—Subgrade, subbase, and base course preparation, p. 35

9.2—Transporting RCC, p. 36

9.3—Trial construction using test strips, p. 36

9.4—Placement, p. 37

9.5—Compaction, p. 38

9.6—Troubleshooting, p. 43

CHAPTER 10—INSPECTION AND TESTING, p. 45

10.1—General, p. 45

10.2—Preconstruction inspection and testing, p. 45

10.3—Construction inspection and testing, p. 46

10.4—Post-construction inspection and testing, p. 47

CHAPTER 11—REFERENCES, p. 48

Authored references, p. 49

APPENDIX—MIXTURE PROPORTIONING BASED ON SOIL COMPACTION, p. 50

A.1—Analogy method, p. 50

CHAPTER 1—INTRODUCTION

Roller-compacted concrete (RCC) is an economical, fast construction candidate for many pavement applications. Because of its relatively coarse surface, RCC has traditionally been used for pavements carrying heavy loads in low-speed areas. In recent years, however, its use in commercial areas and for local streets and highways is increasing.

This guide is largely based on Harrington et al. (2010). The review panel for the Harrington report was made up largely of ACI Committee 327 members. With the cooperation of the Portland Cement Association, the report was used as the basis for this guide. Extensive changes were made during the committee review, including incorporating material from ACI 325.10R. Additional references and examples have been added.

CHAPTER 2—NOTATION AND DEFINITIONS

2.1—Notation

C	=	coefficient relating flexural and compressive strength with values ranging from 9 to 11
E	=	modulus of elasticity, psi (MPa)
f_r	=	flexural strength (third-point loading), psi (MPa)
f_c'	=	compressive strength, psi (MPa)
h	=	slab thickness, in. (mm)
k	=	modulus of subgrade reaction, psi/in. (MPa/mm)
σ	=	stress, psi (MPa)
ϵ	=	strain, in./in. (mm/mm)

2.2—Definitions

ACI provides a comprehensive list of definitions through an online resource, “ACI Concrete Terminology,” <http://www.concrete.org/Tools/ConcreteTerminology.aspx>. Definitions provided herein complement that source.

curling—out-of-plane deformation of the corners, edges, and surface of a pavement from its original shape due to differential temperature within the pavement.

warping—out-of-plane deformation of the corners, edges, and surface of a pavement from its original shape due to differential moisture within the pavement.

CHAPTER 3—KEY ELEMENTS

3.1—Performance comparison of RCC to conventional concrete pavement

Roller-compacted concrete (RCC) gets its name from the heavy vibratory steel drum and rubber-tired rollers used to compact it into its final form. Roller-compacted concrete has similar strength properties and consists of the same basic ingredients as conventional concrete—well-graded aggregates, cementitious materials, and water—but has different mixture proportions. The biggest difference between RCC and conventional concrete mixtures is that RCC has a higher percentage of fine aggregates that allow for tight packing and compaction.

Fresh RCC is stiffer than typical zero-slump conventional concrete, with a consistency that is stiff enough to remain stable under vibratory rollers, yet wet enough to permit adequate mixing and distribution of paste without segregation.

RCC is typically placed with an asphalt-type paver equipped with a standard or high-density screed, followed by a combination of passes with rollers for compaction. Final compaction is usually achieved within 1 hour of mixing. Unlike conventional concrete pavements, RCC pavements are constructed without forms, dowels, or reinforcing steel. Joint sawing is not required, but when sawing is specified, transverse joints are spaced farther apart than with conventional concrete pavements.

RCC pavements are strong, dense, and durable. These characteristics, combined with construction speed and economy, make RCC pavements an excellent alternative for parking and storage areas including port, intermodal, and military facilities; highway shoulders; streets; and highways. RCC can also be used in composite systems as base material.

The use of RCC in public and private applications has been increasing steadily in recent years (Fig. 3.1), particu-

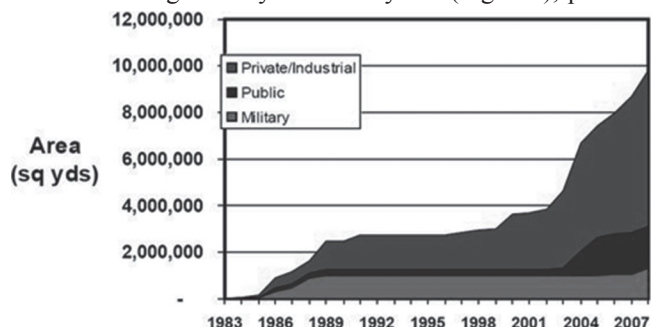


Fig. 3.1—Increasing use of RCC pavements (Pittman and Anderton 2009). (Note: 1 yd² = 0.8 m².)

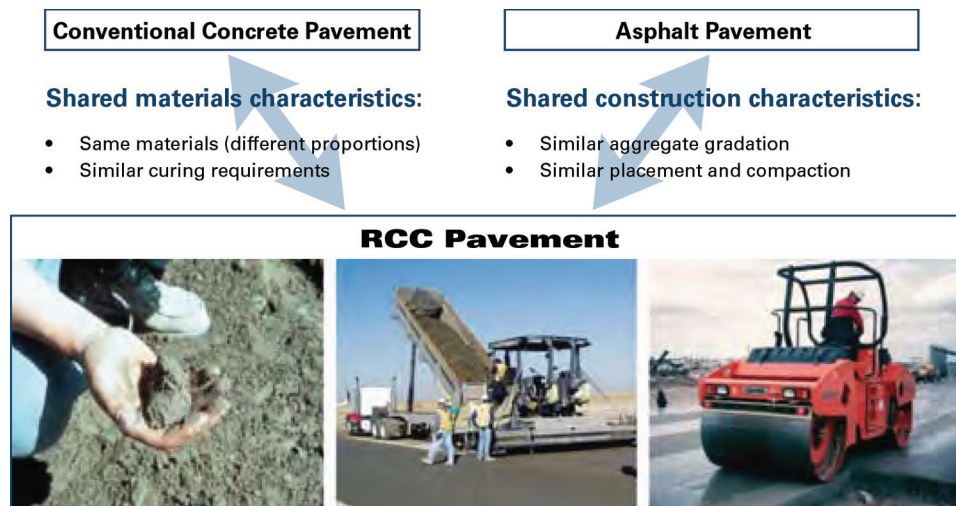


Fig. 3.2a—RCC combines aspects of conventional concrete and hot-mix asphalt paving materials and construction practices (Harrington et al. 2010).

larly in the construction of low-volume roads and parking lots (Pittman and Anderton 2009).

3.2—Materials and structural performance properties

RCC pavements combine various aspects of conventional concrete pavement material practices with construction practices typical of asphalt pavements (Fig. 3.2a). However, while RCC pavements are compacted in the same manner and have similar aggregate gradation (Chapters 5 and 6) as asphalt pavements (Fig. 3.2b), the materials and structural performance properties of RCC are similar to those of conventional concrete pavement.

With well-graded aggregates, proper cement and water content, and dense compaction, RCC pavements can achieve strength properties equal to those of conventional concrete, with low permeability.

RCC mixtures should be dry enough to support the weight of a vibratory roller after placement, yet wet enough to ensure an even distribution of paste. Proper proportioning is essential for ensuring that the mixture has sufficient paste to coat the aggregate particles and fill the voids of the compacted mixture. Coating the aggregate particles is essential to obtain a strong and durable pavement and ensure load transfer through aggregate interlock.

Compaction is the process by which the aggregate particles in the RCC mixture are forced closer together, reducing the amount of air voids in the mixture and increasing the density of the pavement structure. Increased density makes the pavement suitable for load-bearing applications. Rolling should occur before cement hydration begins to harden the paste between the aggregate particles.

Achieving proper density during the rolling process helps prevent non-uniform compaction and isolated weak areas. Depending on the specific mixture and laydown equipment used, external mechanical compaction by rollers could result in a 5 to 20 percent reduction in volume and pavement thickness.

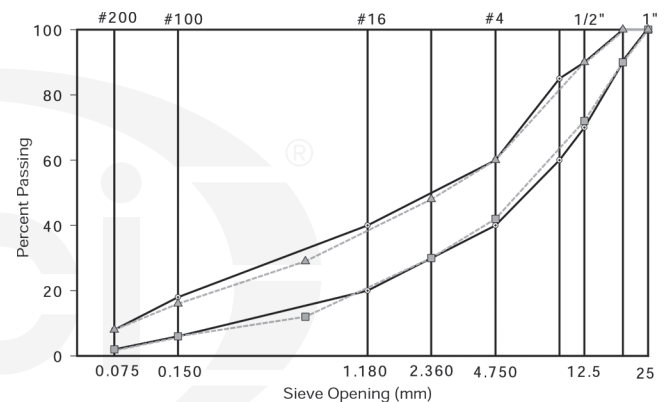


Fig. 3.2b—Aggregate gradation of RCC (without symbols) is similar to aggregate gradation of intermediate HMA layer (with symbols) (Harrington et al. 2010).

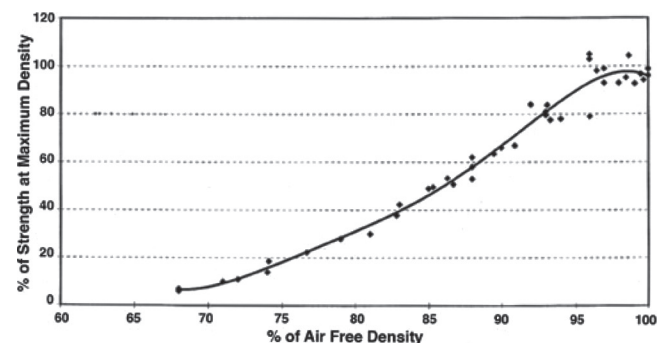


Fig. 3.2c—Strength versus density for various RCC mixtures (Schrader 1992).

Minimizing air void content in the RCC mixture is crucial to its durability. Excess air voids allow penetration of air and water. Non-entrained air weakens the mixture, while excessive water can weaken the mixture and also cause materials-related distresses in the aggregates and damage from freezing and thawing (F-T).

Table 3.3—Comparison of conventional concrete and RCC materials and construction practices

General materials and practices	Pavement type	
	Conventional concrete pavements	RCC pavements
Mixture materials proportions	Well-graded coarse and fine aggregates typically account for 60 to 75 percent of the mixture by volume. A typical w/cm is 0.40 to 0.45, which makes a cement paste wet enough to thoroughly coat the aggregate particles and fill spaces between them.	Dense- and well-graded coarse and fine aggregates typically comprise 75 to 85 percent of RCC mixtures by volume. RCC mixtures are drier than conventional concrete due to their higher fines content and lower cement and water contents.
Workability	The mixture is plastic and workable so that it can be manipulated by the paving machine and relatively stiff (slump is generally approximately 2 in. [50 mm]) to hold shape after extrusion from the paving machine.	The mixture has the consistency of damp, dense-graded aggregates. RCC's relatively dry and stiff (less than zero slump) mixture is not fluid enough to be manipulated by traditional concrete paving machines.
Paving	The mixture is placed ahead of a slipform paving machine, which then spreads, levels, consolidates through vibration, and extrudes the concrete. Typical thicknesses are 8 to 12 in. (200 to 300 mm) but can be greater.	Typically, the RCC mixture is placed with a heavy duty, self-propelled asphalt paving machine, using a high-density single- or double-tamper bar screed to initially consolidate the mixture to a slab of uniform thickness. These types of pavers are essential to high-quality placement, especially in thick pavement applications. Forms are not required. RCC is usually placed in lifts of 6 to 8 in. (150 to 200 mm) with a 4 in. (100 mm) minimum and 10 in. (250 mm) maximum.
Compaction (primarily the removal of non-entrained air)	Compaction occurs internally. Initially, internal vibrators and surface vibrators on the paving machine vibrate the plastic concrete, releasing air. After the concrete is extruded from the machine and before initial set occurs, additional compaction occurs through the settlement of solids (cements and aggregates) and the upward movement of water to the surface (bleeding).	Compaction is accomplished externally by compacting the concrete with rollers, typically within the first 60 minutes after mixing and before the paste begins to harden.
Finishing	Finishing is conducted before initial set occurs. Conventional concrete is usually mechanically textured to improve friction.	Although the surface of RCC pavement typically has an open texture similar to asphalt, use of smaller aggregates, additional cement, or both, can create a denser surface that is closer to that of conventional concrete. RCC can be textured through diamond grinding.
Hydration	Proper hydration of the concrete mixture is critical to the long-term durability of the concrete pavement. To assist in hydration, it is essential to cure the concrete.	Proper hydration of the RCC mixture is critical to its long-term durability. To assist in hydration, it is essential the concrete be cured.
Curing	Thorough curing is required as soon as possible after finishing. This is critical for controlling water evaporation from the concrete surface so that it is available for cement-water hydration, which results in a strong, hardened paste that fills voids and binds aggregate particles.	Thorough curing is required as soon as possible after roller compacting. This controls water evaporation from the concrete surface so that it is available for cement-water hydration, which results in a strong, hardened paste that binds the aggregate particles.
Cracking, load transfer, and reinforcement	In conventional jointed pavements, the crack location is controlled by cutting joints, across which transverse dowel bars are used for load transfer for pavements 8 in. (200 mm) or thicker, and longitudinal tie bars are used to help ensure aggregate interlock. In continuously reinforced pavements, tight cracks are allowed to occur in a naturally closely spaced pattern and the steel reinforcement, together with aggregate interlock, assists in load transfer.	Joints are not usually sawed in RCC industrial applications. When sawing is not specified, random cracks 15 to 30 ft (4.6 to 9.1 m) apart are tight to enable load transfer through aggregate interlock. When sawing is specified to control random cracks, it is typically in applications with car and truck traffic. Fewer joints are sawed in RCC than in conventional concrete pavements, and they are spaced farther apart (15 to 30 ft [4.6 to 9.1 m] transversely). Because of the way RCC is consolidated, it is not possible to place dowels or tie bars in RCC pavements.

The best performance characteristics are obtained when RCC is reasonably free of segregation and is consistently compacted throughout the entire lift at, or close to, maximum density. The strength of RCC drops appreciably as its density drops (Fig. 3.2c) (Schrader 1992; Delatte and Storey 2005).

3.3—Performance differences between RCC and conventional concrete pavement

Table 3.3 shows a comparison of conventional concrete and RCC materials and construction practices. RCC mixtures typically have a lower volume of cementitious materials, coarse aggregates, and water than conventional concrete mixtures, and a higher volume of fine aggregates, which fill the air voids in the pavement system (Fig. 3.3a). Fine aggregates

gates in RCC are more closely packed than in conventional concrete (Fig. 3.3b). This close packing initially provides a high-friction aggregate interlock between the particles and contributes to the pavement's initial load-carrying capacity.

Construction of concrete pavements involves mechanical compaction and chemical hydration processes. For conventional concrete pavement, compaction occurs through internal paving machine vibrators. Through the hydration process, the paste hardens to bind the aggregate particles together. For RCC pavements, compaction occurs through conventional or high-density paving screeds followed by steel drum and rubber-tired rollers. As with conventional concrete, the paste hardens through hydration to bind aggregate particles together within the RCC mixture. The result is a dense pavement that has properties similar to those of conventional concrete pavement.

Immediately following placement, conventional concrete remains in a plastic state until hydration begins to harden the paste and bind the aggregates together. Conventional concrete pavement does not have enough load-carrying capacity to support occasional light vehicle traffic until the sawing window is reached or passed.

In contrast, RCC has enough load-carrying capacity to support occasional light vehicle traffic, such as a car entering

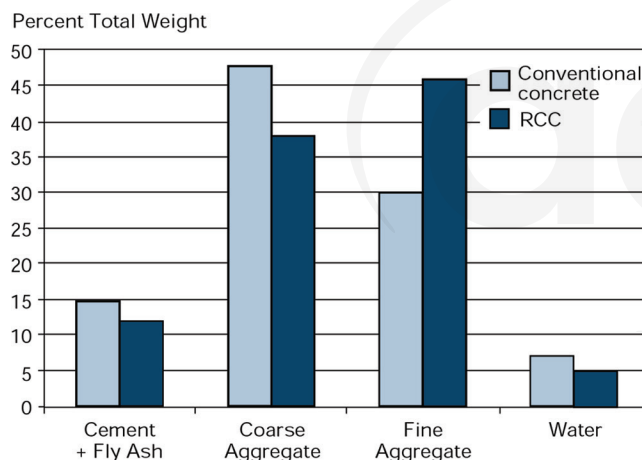


Fig. 3.3a—Typical material comparisons of conventional concrete and RCC (Harrington et al. 2010).

or leaving a driveway, immediately following placement. This is shown in Fig. 3.3c. This load-carrying capacity is due to the compaction process, which creates friction between the confined particles, also known as aggregate interlock, and allows an occasional light vehicle to be placed on the RCC without damaging or disrupting the in-place material. Traffic beyond the occasional light vehicle, however, is not recommended until both RCC and conventional concrete achieve adequate compressive strength between approximately 2000 and 2500 psi (14 and 17 MPa).

RCC is an economical, fast-construction candidate for many pavement applications (Piggott 1987). Traditionally used for pavements carrying heavy loads in low-speed areas because of its relatively coarse surface, in recent years its use in commercial areas and for local streets and highways has increased.

Typical applications include:

- a) Industrial plant access roads and parking lots
- b) Intermodal shipping yards, ports, and loading docks
- c) Truck/freight terminals, bulk commodity storage, and distribution centers
- d) Low-volume or low-to-moderate-speed urban and rural roads
- e) Aircraft parking areas
- f) Military tank trails and parking pads
- g) Military long- or short-term loading zones, forward or rearward bases of operation, and airfields
- h) Recreational vehicle pad storage
- i) Vehicle maintenance areas or compost areas
- j) Large commercial parking lots
- k) Roadways in public parks
- l) Roadways for timber and logging operations
- m) Highway shoulders
- n) Temporary travel lanes that should be constructed quickly to divert traffic

RCC can be used in pavement systems serving higher traffic speeds. For example, it can be used as overlays or as a base for conventional concrete pavement surfaces or as the lower lift in a two-lift paving operation. Refer to [Chapter 4](#) for more detailed information about its use.

The typical surface texture of RCC is more open than that of conventional concrete, similar to the open texture of asphalt. However, a denser, more closed surface texture is

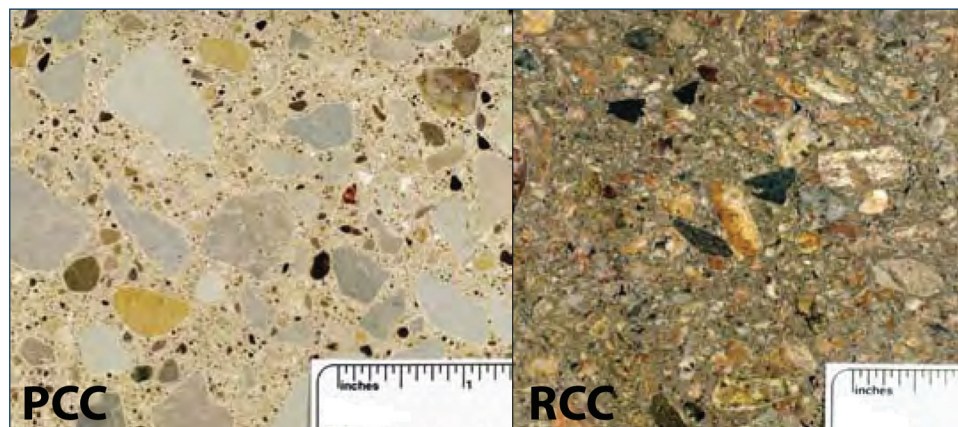


Fig. 3.3b—Comparison of the aggregate distribution of: (a) conventional portland cement concrete (PCC); and (b) RCC (Harrington et al. 2010).

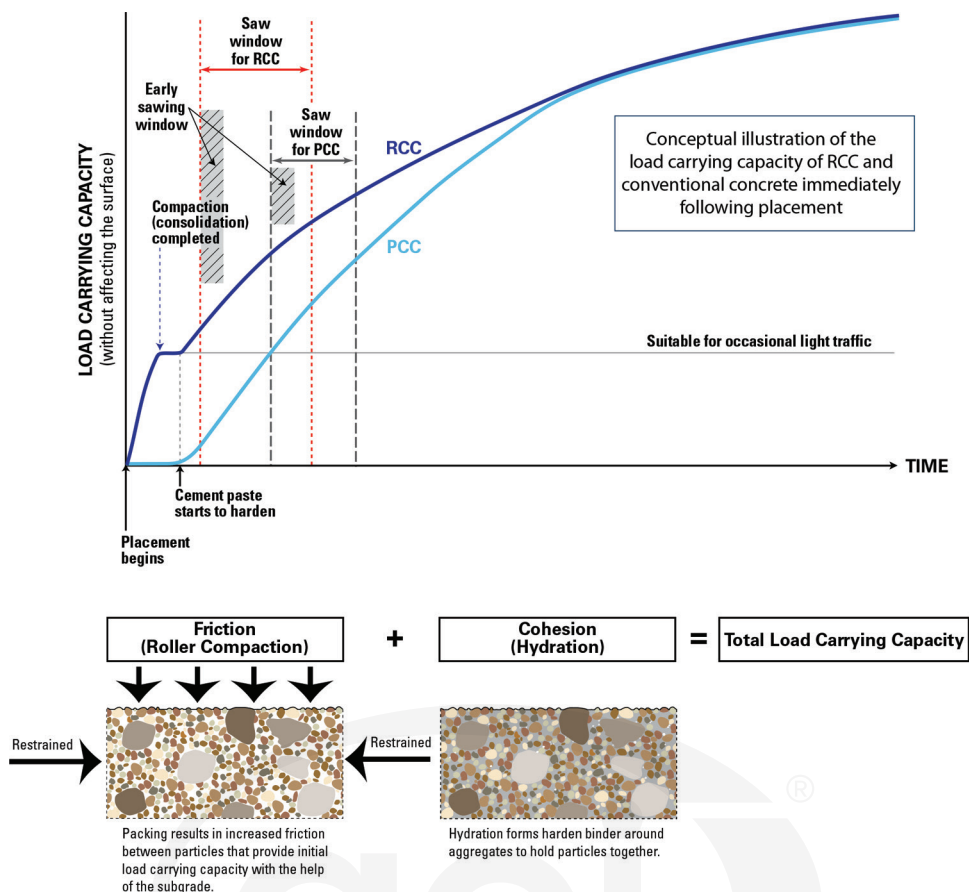


Fig. 3.3c—Load-carrying capacity of conventional concrete and RCC over the first few days (Harrington et al. 2010).



Fig. 3.3d—Surface texture of RCC after diamond grinding (Harrington et al. 2010).

achieved by diamond grinding (Fig. 3.3d and 3.3e) or using a thin overlay.

3.4—Benefits of RCC

Construction cost histories of RCC and conventional concrete show that RCC unit cost is often lower than an equivalent section of conventional concrete or asphalt pave-



Fig. 3.3e—Diamond grinding of RCC provides for a smooth and quiet surface. Diamond ground section is behind vehicle.

ment (Adaska 2006). The specific percentage of savings depends on the complexity and amount of concrete placed.

The savings and benefits associated with RCC use over conventional concrete are primarily due to reduction in cement content, forming and placement costs, and construction times. Because of the dry consistency of RCC, there is no need for forms or finishing. Also, dowels, tie rods, and steel reinforcement bars are not incorporated in RCC because its dry consistency could inhibit bonding, and the roller compaction could result in bar misalignment.

Other benefits include (Portland Cement Association 2007b):

- a) A lower paste content that results in less concrete shrinkage and reduced cracking from shrinkage-related stresses
- b) The ability to be designed with high flexural, compressive, and shear strengths, which allow it to support heavy, repetitive loads without failure, such as in heavy industrial, mining, and military applications
- c) The ability to withstand highly concentrated loads and impacts
- d) The ability to provide excellent durability and resistance to chemical attack, even under freezing and thawing conditions because of low permeability
- e) Asphalt rutting and subsequent repairs are eliminated, as for other rigid pavements, except in areas of heavy tire chain or studded tire use
- f) Time and costs related to joint maintenance can be eliminated because sawed joints are usually not required for industrial applications such as waste yards, logging facilities, and tank pads
- g) RCC can also be resistant to salt scaling
- h) A resistance to abrasion that is similar to conventional concrete pavement, even under heavy loads and high traffic volumes
- i) The light surface color of RCC pavements reduces lighting requirements for parking and storage areas
- j) Occasional light vehicles, such as cars and light trucks, can travel at low speeds on RCC pavements soon after completion without causing damage
- k) Can use both natural and manufactured fine aggregates
- l) Fine aggregates unsuitable for asphalt pavements can be used in RCC
- m) The ability to be placed in lifts as thick as 10 in. (250 mm), depending on the mixture, and use of high-density pavers
- n) RCC pavements have a solar reflectance index (SRI) greater than the minimum for Leadership in Energy and Environmental Design (LEED) points (LEED 2013)
- o) RCC resistance to freezing and thawing is high, even without air entrainment.

3.5—Sustainability

Selecting RCC for appropriate applications results in a sustainable pavement that meets the economic, environmental, and social demands of today's infrastructure. They are a sustainable option because they have:

- a) Low embodied primary energy due to low production and maintenance energy use

- b) Reduced construction fuel demand compared to asphalt pavements, due to thicker lifts

- c) The ability to use natural aggregates in the most cost-effective manner, by eliminating the need for substantial granular subbase while providing high structural load-carrying capacity

- d) The ability to consume industrial by-products, such as fly ash, slag cement, and silica fume

- e) The ability to use more non-plastic fines (material passing the No. 200 [0.075 mm] sieve with low or no plasticity), which reduces waste materials at quarries

- f) Longevity

- g) Low pavement deflection, which increases fuel economy

- h) Recyclability for use as future concrete or granular base

- i) High heat and light reflectance

3.6—Potential limitations

Agencies and contractors should be aware of the possible limitations and challenges associated with RCC pavement:

- a) Without diamond grinding, RCC's profile and smoothness may not be desirable for pavements carrying high-speed traffic.

- b) The amount of RCC that can be mixed in a transit mixer or concrete truck is typically lower than for conventional concrete, due to the dryness of the RCC mixture (Chapter 8).

- c) Multiple horizontal lifts and adjacent slabs should be placed within 1 hour of each other to ensure good bonding, unless a cold joint is planned, in which case, refer to Chapter 9.

- d) Pavement edges are more difficult to compact, so most specifications require 96 percent modified Proctor density on cold joints instead of the 98 percent required on interior pavement sections. History has shown that properly prepared and consolidated cold joints perform very well (Chapter 9).

- e) Due to relatively low water content, hot-weather RCC paving requires extra vigilance to minimize water loss to evaporation.

- f) Due to RCC mixture dryness, admixture dosage requirements can be higher for RCC than for conventional concrete (Chapter 5).

CHAPTER 4—COMMON USES

This chapter outlines many of the common uses of RCC pavements. This summary of typical pavement criteria for different RCC uses is based on over 30 years of industry performance experience. A directory of projects prepared by the American Concrete Pavement Association (2014) is available.

Although many RCC applications do not require jointing, joints can be sawed to initiate crack locations, improve aesthetic appearance, or minimize crack openings for improved load transfer (Chapters 7 and 9). Early RCC pavements were constructed without joints and allowed to crack naturally (Piggott 1987).

To provide the most cost-effective solution to meet the desired expectations, consider the unique characteristics of each RCC application. In Table 4.1 and the following sections (4.1

Table 4—Common RCC applications

Application	Traffic type	Design	Surface characteristics
Ports and heavy industrial	Heavy trucks at < 30 mph (48 km/h)	U.S. Army Corps of Engineers (2009) or RCC-PAVE	3/8 in. (9.5 mm) maximum variance in 10 ft (3 m)
Light industrial areas	Heavy trucks at < 30 mph (48 km/h)	ACI 325.12R and 330R, StreetPave, WinPAS, U.S. Army Corps of Engineers (2009), or RCC-PAVE	3/8 in. (9.5 mm) maximum variance in 10 ft (3 m)
Airport service areas	Maintenance, airport parking, snow storage	ACI 325.12R and 330R, AirPave, StreetPave, WinPAS, U.S. Army Corps of Engineers (2009), or RCC-PAVE	Aprons, taxiways, and runways require surface course
Arterial streets	Buses, cars, trucks	ACI 325.12R and 330R, StreetPave, WinPAS	Surface course or diamond grinding
Local streets	Buses, cars, trucks	ACI 325.12R and 330R, StreetPave, WinPAS	Surface course or diamond grinding if posted speeds exceed 30 mph (48 km/h)
Widening and shoulders	Buses, cars, trucks	Thickness typically established by standards for shoulders. ACI 325.12R, StreetPave, or WinPAS	Surface course or diamond grinding for widening
Multilayer pavements for high-speed use	High-volume truck, bus, and car traffic	AASHTO (1993), AASHTO M-E PDG, StreetPave, or WinPAS	Surface course of asphalt or concrete
Logging facilities and storage yards	Slow heavy equipment	U.S. Army Corps of Engineers (2009) or RCC-PAVE	3/8 in. (9.5 mm) maximum variance in 10 ft (3 m)

*Fig. 4.1—Example of RCC port facility in Houston, TX (Harrington et al. 2010).*

through 4.8) are consideration factors for several of the most common RCC pavement applications.

4.1—Ports, intermodal facilities, and heavy industrial facilities

Ports and heavy industrial facilities are large, open areas with few obstructions that could delay the construction process, making them ideal candidates for RCC. Pavements for ports and other heavy industrial facilities should be strong and durable because container handling equipment can have wheel loads of 30 to 60 kips (13.6 to 27.2 metric tons) or more per tire (Fig. 4.1). Military facilities handling heavy vehicles also fall into this category (Hutchinson et al. 1987). In applications where the desired thickness is greater than 10 in. (254 mm), two lifts are required.

For channelized traffic areas, such as entrance roads and designated truck lanes, edge loading should be considered in the analysis. To avoid overdesign of the RCC pavement

interior, where it is not subject to edge loading, thickened edges or wider sections should be considered.

4.1.1 Surface treatment—Surface appearance and texture are a consideration, but are generally not of primary concern. The surface smoothness typically has a 3/8 in. (9.5 mm) maximum variance for a 10 ft (3 m) straightedge. Low traffic speeds of less than 30 mph (48 km/h) allow for unsurfaced RCC pavement.

4.1.2 Sawed joints—Joints may be sawed into the RCC pavement, or the pavement may be allowed to crack naturally. Because random cracks in RCC pavements are generally tight and aesthetics are not a major factor for heavy use, saw cutting of joints is usually not required. In open storage and loading areas where concentrated lane traffic is uncommon, joints can be sawed in square patterns using transverse spacing of 15 to 20 ft (4.6 to 6.1 m) intervals for pavements less than 8 in. (200 mm) thick and three to four times the pavement thickness for pavements 8 in. (200 mm) thick or greater. In areas where concentrated lane loading

is required, the longitudinal spacing should be 15 to 20 ft (4.6 to 6.1 m) for pavements less than 8 in. (200 mm) thick and 2.5 times (in feet) the pavement thickness (in inches) for pavements 8 in. (200 mm) thick or greater.

Installation of joints should be considered for access roads and areas of channelized traffic at speeds greater than 30 mph (48 km/h) or for aesthetic reasons.

4.2—Light industrial areas

Similar to heavy industrial areas, light industrial areas, such as warehouse and auto manufacturing facilities, provide a large uninterrupted space that is ideal for RCC (Fig. 4.2). Traffic speeds are typically below 30 mph (48 km/h) and, therefore, require no surface treatments. Vehicle loading is lower than for ports and other heavy duty facilities requiring little use of multiple-lift construction. RCC is also ideal for access roads within the industrial complex. For channelized traffic areas, such as entrance roads and designated truck lanes, edge loading should be considered in the analysis.

4.2.1 Surface treatment—Surface appearance and texture are a consideration, but are not of great importance in the truck traffic areas. In the parking areas and those where appearance and texture are important, consider using 5/8 in. (16 mm) nominal maximum size of aggregate (NMSA) and jointing the pavement. Surface smoothness typically has a 3/8 in. (9.5 mm) maximum variance for a 10 ft (3 m) straightedge. Unsurfaced RCC pavements are acceptable when traffic speeds are 30 mph (48.3 km/h) or less.

4.2.2 Sawed joints—Because random cracks in RCC pavements can be tight and aesthetics are not typically a factor for heavy-duty use, saw cutting of joints is typically not required.

Joints may be sawed to initiate crack locations or to improve aesthetics in parking lots, access roads, or areas of channelized traffic at speeds greater than 30 mph (48 km/h). In open storage and loading areas where concentrated lane traffic is uncommon, joints can be sawed in square patterns spaced using the transverse spacing of 15 to 20 ft (4.6 to 6.1 m) intervals for pavements less than 8 in. (200 mm) thick and three to four times (in feet) the pavement thickness (in inches) for pavements 8 in. (200 mm) thick or greater. In areas with concentrated lane loading, the longitudinal spacing should be 15 to 20 ft (4.6 to 6.1 m) for pavements less than 8 in. (200 mm) thick and 2.5 times (in feet) the pavement thickness (in inches) for pavements 8 in. (200 mm) thick or greater. Joint installation should be considered for access roads and areas of channelized traffic at speeds greater than 30 mph (48 km/h) or for aesthetic reasons.

4.3—Airport service areas

Airports use unsurfaced RCC pavements for maintenance areas, parking lots, and snow storage areas because it can withstand large loads, such as heavy snow plowing and truck traffic, and it will not deteriorate under the saturated conditions caused by melting snow.

4.3.1 Surface treatment—Lower-speed-traffic parking areas and maintenance equipment areas typically do not



Fig. 4.2—Example of RCC distribution center, Austin, TX, 10 years after construction (Harrington et al. 2010).



Fig. 4.3.1—Pavement cores showing multilayer system with geotextile fabric layer (Harrington et al. 2010).

require any smoothness specification or surface treatment. Composite sections made up of an RCC base with a thin overlay of asphalt or unbonded concrete have been used for runways, taxiways, and aprons (Fig. 4.3.1). Unsurfaced RCC pavements are not recommended for airplane traffic due to the possible dislodging of loose surface aggregate in the first 2 years.

4.3.4 Sawed joints—Sawed joints are not required in maintenance areas. Sawing may be desired to initiate crack openings and for aesthetic reasons in parking lots.

4.4—Arterial streets

Traffic is of major concern when paving arterial streets. Due to traffic constraints and the time required to place multiple asphalt lifts, some agencies have chosen to use a single lift of RCC pavement to pave arterial streets. RCC pavements can be constructed rapidly, reducing both project and user costs. RCC may also be used for inlays to replace rutted flexible pavement (Portland Cement Association 2005).

As an example of this type of application, the reconstructed Lane Avenue pavement in Columbus, OH (Fig. 4.4), consists of 8 in. (200 mm) of RCC surfaced with 3 in. (75 mm) of asphalt to provide smoothness for the higher speed traffic. The RCC pavement was constructed under traffic for



Fig. 4.4—RCC pavement constructed on an arterial street in Columbus, OH (Harrington et al. 2010).

this four- to six-lane arterial street (Portland Cement Association 2005).

Another example is the 2009 reconstruction of US 78 in Aiken, SC, where a 10 in. (250 mm) RCC pavement replaced an existing full-depth asphalt pavement. The RCC surface was diamond-ground for this four-lane section, improving the smoothness and providing surface texture at an affordable cost.

4.4.1 Surface treatment—Due to their higher traffic speeds, most arterial streets include a surface treatment such as diamond grinding or a thin 2 to 3 in. (50 to 75 mm) asphalt surface course. If the required pavement thickness exceeds 10 in. (250 mm), a good alternative is to construct the bottom section with RCC and place an unbonded conventional concrete overlay over the RCC.

4.4.2 Sawed joints—Sawed joints are typically used when the surface is diamond-ground or when an asphalt surface course is used. The asphalt is sometimes jointed directly over the jointed RCC for aesthetic reasons and uniform maintenance.

Transverse joints should be spaced at 15 to 20 ft (4.6 to 6.1 m) intervals for pavements less than 8 in. (200 mm) thick and three to four times (in feet) the pavement thickness (in inches) for pavements 8 in. (200 mm) thick or greater. Longitudinal joints should be spaced 15 to 20 ft (4.6 to 6.1 m) for pavements less than 8 in. (200 mm) thick and 2.5 times (in feet) the pavement thickness (in inches) for pavements 8 in. (200 mm) thick or greater. Care should be taken to ensure that joints are not placed in the wheel path. For multilayer systems with RCC as a base, the concrete overlay uses conventional concrete joint spacing.

4.5—Local streets

Speed of construction, economy, and early opening to traffic are key reasons to use RCC for streets and local roads (Fig. 4.5). In addition, using RCC for new residential developments provides a strong working platform during site work and construction. Surface treatments can be applied when the development nears completion (Portland Cement Association 2005).



Fig. 4.5—Example of RCC pavement used for a local street (Harrington et al. 2010).

When traffic speeds are greater than 30 mph (48 km/h), surface smoothness is important. To achieve better surface smoothness, most projects use high-density pavers, diamond grinding, or both. A thin asphalt surface course placed on top of the RCC is another option. In some cases, light traffic has been allowed on the RCC pavement within 24 hours after construction to accommodate nearby businesses.

4.5.1 Surface treatment—Surface smoothness typically has a 3/8 in. (9.5 mm) maximum variance for a 10 ft (3 m) straightedge. For traffic speeds 30 mph (48 km/h) or lower, surface treatments such as diamond grinding and asphalt surface courses are typically not required to meet smoothness specifications. If a tighter, more closed surface is desired, a 5/8 in. (16 mm) nominal maximum size of aggregate (NMSA) can be used to tighten the surface. If posted speeds exceed 30 mph (48 km/h), either a diamond grinding or an asphalt surface course is needed at the time of project opening.

4.5.2 Sawed joints—Sawed joints may be desired to initiate crack locations, or for aesthetic reasons in residential areas. Transverse joints should be spaced at 15 to 20 ft (4.6 to 6.1 m) intervals for pavements less than 8 in. (200 mm) thick and three to four times (in feet) the pavement thickness (in inches) for pavements 8 in. (200 mm) thick or greater. Longitudinal joints should be spaced 15 to 20 ft (4.6 to 6.1 m) for pavements less than 8 in. (200 mm) thick and 2.5 times (in feet) the pavement thickness (in inches) for pavements 8 in. (200 mm) thick or greater.

4.6—Widening and shoulders

In the United States, there are areas where widening roadways is a common solution to meeting new lane and edge drop-off criteria. In many instances, the road is widened into areas where soil and road foundation conditions are poor. The strength of RCC and its speed of construction make it particularly suited to road-widening applications. The material provides a stable foundation that can be surfaced with asphalt or concrete for highway traffic and is one that provides a long, low-maintenance life (Portland Cement Association 2005).

Distressed pavement in shoulders can also be replaced with RCC. The benefits of the material make RCC a viable option for pavement designers. For example, the Georgia

Department of Transportation used RCC to reconstruct road shoulders on I-285 (Kim 2006) (Fig. 4.6). The existing asphalt shoulders were badly distressed and required reconstruction. The existing shoulder was milled out and replaced with a 10 ft (3 m) wide and 6 to 8 in. (150 to 200 mm) deep section of RCC. Rumble strips were ground into the surface to conform to interstate highway safety requirements. The project included 34 shoulder miles (55 km) of RCC. No surfacing was placed on the RCC.

4.6.1 Surface treatment—For shoulder applications, surface smoothness typically has a 3/8 in. (9.5 mm) maximum variance for a 10 ft (3 m) straightedge. Rumble strips may be specified for high-speed facilities. For widening applications, diamond grinding or a thin asphalt or concrete overlay is used to provide adequate smoothness.

4.6.2 Sawed joints—Sawed joints are typically not required for shoulders or widening. If required, the transverse joints are sawed at the same location as on the mainline.

4.7—Multilayer pavement systems for high-speed uses

For roadways carrying traffic at highway speeds, RCC is currently used primarily as a base under a thin asphalt wearing course for rideability. Another possibility, however, is to use RCC as a base under a conventional concrete pavement. RCC provides an excellent construction platform and allows for the final concrete pavement surface thickness to be reduced.

For example, to design a long-term pavement greater than 10 in. (250 mm) thick with a surface renewal limited to a 30- to 40-year cycle, one option would be to use a wet-on-dry multilayer system that would consist of an RCC base under a 4 to 6 in. (100 to 150 mm) concrete pavement. A separation layer between the RCC base and concrete pavement is required to allow for separate layer movement and to create a shear plane that relieves stress and helps prevent cracks from reflecting up from the base into the concrete pavement surface.

A similar system consisting of a cement-treated base with a geotextile fabric layer and an unbonded concrete overlay has been used successfully in Germany for nearly 20 years.

4.7.1 Surface treatment—A conventional concrete surface or asphalt-wearing course is typical. Surface smoothness typically has a 3/8 in. (9.5 mm) maximum variance for a 10 ft (3 m) straightedge.

4.7.2 Sawed joints—The RCC base is typically not sawed when used under a conventional concrete pavement. The concrete pavement is sawed using a typical concrete pavement jointing pattern. If the RCC base is sawed to minimize crack spacing and improve load transfer, transverse joints should be spaced at 15 to 20 ft (4.6 to 6.1 m) intervals for pavements less than 8 in. (200 mm) thick and three to four times (in feet) the pavement thickness (in inches) for pavements 8 in. (200 mm) thick or greater. Longitudinal joints (if sawed) should be spaced 15 to 20 ft (4.6 to 6.1 m) for pavements less than 8 in. (200 mm) thick and 2.5 times (in feet) the pavement thickness (in inches) for pavements 8 in. (200 mm) thick or greater; care should be taken to ensure that joints are not placed in the wheel path.



Fig. 4.6—Example of RCC used to reconstruct shoulders on I-285 near Atlanta, GA (Harrington et al. 2010).



Fig. 4.8—RCC pavement constructed at a log handling facility (Harrington et al. 2010).

ments less than 8 in. (200 mm) thick and 2.5 times (in feet) the pavement thickness (in inches) for pavements 8 in. (200 mm) thick or greater; care should be taken to ensure that joints are not placed in the wheel path.

4.8—Logging facilities, composting areas, and storage yards

RCC was first used for log handling facilities in Canada in the mid-1970s (Piggott 1987) (Fig. 4.8). This type of application requires pavement strength and durability to support the heavy loads. Surface appearance, texture, and smoothness are of lesser importance for these applications; therefore, coarser aggregates can be used. Road graders and dozers are sometimes used to place the RCC in the most basic applications.

4.8.1 Surface treatment—Typically, no surface treatment is applied. The surface smoothness has an approximately 1/2 in. (13 mm) maximum variance for a 10 ft (3 m) straightedge.

a) Typically, no surface treatment is applied

b) The surface smoothness has an approximately 1/2 in. (13 mm) maximum variance for a 10 ft (3 m) straightedge

4.8.2 Sawed joints—Joints are generally not sawed.

CHAPTER 5—PROPERTIES AND MATERIALS

5.1—Roller-compacted concrete engineering properties

Although the properties of RCC are similar to those of conventional concrete pavement, they are achieved using different mixture proportions and construction techniques. Data describing the engineering properties of RCC pavements are based on tests of cylinders from actual paving projects as well as full-scale test sections.

Tests used to determine RCC engineering properties include [ASTM C1435/C1435M](#), [ASTM D1557](#), [ASTM C39/C39M](#), [ASTM C42/C42M](#), [ASTM C1170/C1170M](#), and [ASTM C78/C78M](#).

5.1.1 Strength—The strength properties of RCC depend on the amount of water, the water-cementitious materials ratio (w/cm) quality of aggregates, and degree of compaction of the concrete. In general, RCC pavements can have compressive and flexural strengths comparable to those of conventional concrete pavements. Mixture design analysis is conducted as necessary to meet design strength criteria.

5.1.1.1 Compressive strength—The compressive strength of RCC is comparable to that of conventional concrete, typically ranging from 4000 to 6000 psi (28 to 40 MPa). Some projects have reached compressive strengths higher than 7000 psi (50 MPa) ([ACI 325.10R](#)); however, practical construction and cost considerations would likely specify increased thickness rather than strengths of this magnitude.

The densely graded aggregates used in RCC mixtures help the concrete achieve high levels of compressive strength. The low w/cm of RCC mixtures produces a low-porosity cement matrix that also contributes to the high compressive strength of the concrete. Every mixture proportion has an optimum moisture content at which it achieves the maximum dry density. This density most often provides the maximum strength. Chapter 6 provides the mixture proportioning steps to achieve the desired mixture design strength.

5.1.1.2 Flexural strength—Flexural strength is directly related to the density and compressive strength of the concrete mixture. In properly constructed RCC pavements, the aggregates are densely packed. The density of the paste and the strength of its bond to the aggregate particles are high due to its low w/cm . As a result, the flexural strength of RCC, depending on the mixture design, is generally high, ranging from 500 to 1000 psi (3.5 to 7 MPa).

There is less information available on the flexural strength of RCC because of the difficulty of obtaining sawed beam specimens from actual paving sites and from the absence of a standardized test method for fabricating beams in the field and laboratory. Based on beams and cores obtained from a test section, the relationship between the compressive and flexural strengths of RCC appears to be similar to that for conventional concrete following Eq. (5.1.1.2).

$$f_r = C\sqrt{f'_c} \quad (5.1.1.2)$$

5.1.2 Modulus of elasticity—The modulus of elasticity expresses the ratio between the applied stress and strain shown as follows

$$E = \sigma/\epsilon \quad (5.1.2)$$

The modulus of elasticity represents the material's propensity to undergo reversible elastic deformation in response to a stress.

Limited tests on RCC cores obtained from a full-scale test section indicate that RCC modulus of elasticity values are similar to or slightly higher than those of conventional concrete when the mixtures have similar cement contents.

5.1.3 Fatigue—Fatigue failure occurs when a material is subjected to repeated stresses. While the stress caused by a single load is not greater than the strength of the material, so the material will not fail, repetition of these loads will wear on the material over time and eventually result in fatigue failure.

Because the critical stresses in RCC pavements are flexural, fatigue due to flexural stress is used for thickness design. Stress ratio, as used in fatigue relationships, is the ratio of flexural stress to flexural strength. For example, if a wheel load causes a flexural stress of 400 psi (2.8 MPa) and RCC flexural strength is 650 psi (4.5 MPa), then

$$\text{stress ratio} = 400/650 = 0.62 \quad (5.1.3)$$

Only limited testing has been conducted to evaluate the fatigue behavior of RCC. The results of fatigue tests performed on beams obtained from a full-scale test section incorporating four different RCC mixtures indicate that the fatigue behavior of RCC is similar to that of conventional concrete ([Tayabji and Okamoto 1987](#)). [Gomez and Scholer \(1989\)](#) found similar results from fatigue testing of laboratory beams compacted using a Vebe table.

5.1.4 Bond strength—Bond strength at the interface of RCC lifts is a critical engineering property. Bond strength determines whether RCC pavements constructed in multiple lifts will behave as a single layer or as partially bonded or unbonded lifts. The load-carrying capacity of partially bonded or unbonded lifts is lower than that of bonded lifts of equal total thickness. Typically, adequate bond strength is achieved when pavement lifts are placed within 1 hour of each other, but placement may need to be quicker in warm weather. Cores should be taken to check for bonding.

Data from test sections indicate that sufficient interface bond strength can be achieved for properly constructed RCC pavements. The data also show, however, that bond strength development along the edges of longitudinal construction joints may be lower than the bond strength in interior locations.

5.1.5 Resistance to freezing and thawing—RCC pavements in northern climates can be subjected to two types of damage caused by freezing-and-thawing (F-T) cycles: internal cracking and surface scaling. While these two types of damage may occur simultaneously, they are distinct and independent. If the RCC contains significant moisture, F-T cycles can produce internal cracking, which reduces the dynamic modulus of elasticity and results in expansion and delamination.

sion. Surface scaling also occurs during F-T cycles when the concrete is exposed to significant moisture. Scaling is the deterioration of the upper concrete slab surface—typically 1/8 to 1/2 in. (3 to 13 mm)—and may occur anywhere over the pavement (Miller and Bellinger 2003). Scaling may also occur with repeated application of deicing salts. This type of scaling may be prevented by using an adequately air-entrained, low-permeability concrete with a low w/c . Risk of scaling is higher on concrete surfaces that have not been finished properly (Mindess et al. 2003). This process worsens in the presence of deicing salts (Marchand et al. 1997). RCC mixtures should, therefore, be designed to resist both types of attack caused by F-T cycles.

Field performance studies have indicated that RCC has performed well in harsh weather conditions. Studies in the United States and Canada indicate that RCC mixtures, whether air entrained or not, have performed well for more than three decades. Piggott (1999) inspected and reported on 34 RCC pavements in United States and Canada. The study concluded that RCC pavements in varied climatic conditions and ranging in age from 3 to 20 years have performed well. The study notes that non-air-entrained RCC pavements can provide reliable and durable performance in F-T environments as long as the mixture has adequate cement content, sound aggregates, adequate compaction, as well as proper mixing and curing.

When considering non-air-entrained RCC for a particular application, careful attention should be paid to the consistent achievement of maximum compacted density as prescribed by lab and field trials. A well-graded, compacted, and proportioned RCC mixture leads to good distribution of entrapped air voids that could reliably resist F-T cycles (Luhr 2006). Gauthier and Marchand (2005) have stated that a properly designed RCC mixture, compacted to 100 percent of the reference wet density, has adequate frost resistance to prevent internal cracking. A study by Pigeon and Marchand (1993) has shown that non-air-entrained RCC mixtures can withstand 300 cycles of freezing and thawing without any deterioration. This finding may suggest that some compaction air voids act as air bubbles. In these authors' investigations, the use of air-entraining admixtures did not result in entraining any significant amount of spherical voids, and it is clear that most of the air voids observed resulted from the compaction operation.

For air-entrained RCC, studies have shown that air-entraining admixtures have a positive influence on the F-T resistance of RCC (Pigeon and Marchand 1993; Portland Cement Association 2004; Hazaree 2007). Note that admixture manufacturers recommend dosages for conventional concrete and not for RCC. Test data clearly demonstrate that very little entrained air is required to adequately protect RCC against frost-induced microcracking and deicing salt scaling. Even when spherical air void content is normally quite low at less than 1 percent, the resistance against frost action is demonstrated when a good air void spacing factor exists from the high content of irregularly shaped compaction voids. A study by Ragan (1991) indicates that the frost resistance of RCC is directly related to the air void spacing

factor and that a minimum spacing factor of 0.01 in. (250 μm) or for a durable concrete is required.

A caveat for air-entrained RCC is to properly select the air-entraining admixture and ensure its compatibility with the mixture type. Because different air-entraining admixtures require different mixing energies and mixing times for entraining a sufficiently stable air void system, the type of air-entraining admixture and mixer play an important role. Previous experience has shown that pan mixers can exhibit a much higher kneading energy than other types of mixtures. This high energy facilitates the introduction of air during the mixing period and the subsequent action of the air-entraining admixture. In addition, air entrainment in RCC can require higher admixture dosages than conventional concrete due to the lower water and cement contents inherent in the stiffer RCC mixture. Therefore, proper admixture selection and laboratory validation are necessary.

There are several important considerations for frost-resistant RCC pavement:

a) Material selection for freezing-and-thawing-resistant RCC is similar to that for conventional concrete pavement. Aggregate selection is based on the routine screening process. Any mineral aggregate evaluated and found suitable for a particular F-T environment in conventional concrete pavements can be used in RCC with equal confidence. Sound, durable, weather-resistant aggregates meeting the quality requirements of ASTM C33/C33M should be specified.

b) Selection of a dense, well-graded aggregate ensures optimum compaction and maximum density in the field. Not only will it provide the highest strength at the minimum cement content, it will also provide a tight, minimally permeable surface less likely to allow water to penetrate.

c) Quantity and selection of cement binders is important. Adequate cement content is necessary to provide sufficient strength. Maintaining a w/cm below 0.40 has proven beneficial to obtaining the necessary strength and reducing permeability. Water-reducing chemical admixtures help achieve this low w/cm while providing adequate workability. Studies in Canada indicate that the use of supplementary cementitious materials (SCMs), such as silica fume, helps F-T performance, particularly with scaling resistance. Silica fume improves the mechanical properties of RCC and speeds up mechanical strength development (Gauthier and Marchand 2005; Portland Cement Association 2004). Silica fume is used mostly in blended cements, at a level of replacement of 7 to 8 percent. Other SCMs are used with proper selection, evaluation, and consideration regarding production, placement, compaction, and weather conditions.

d) Compacting RCC to the highest possible density provides the greatest potential for high strength and low permeability, which are two key factors in achieving durable, frost-resistant RCC (Luhr 2006).

e) Curing plays a critical role in providing freezing-and-thawing-resistant RCC, especially at the pavement surface. Throughout the construction phase, from mixing to finishing operations, sufficient care should be taken to ensure that excessive evaporation of moisture from the surface does not occur. Because RCC has no bleed water, premature surface drying

is a concern. If precautions are not taken to minimize moisture loss from the surface, the drying may weaken the RCC surface, thereby reducing its ability to resist F-T damage. On completion of RCC compaction, the surface should be kept continuously damp to prevent moisture loss until a curing compound is properly applied.

Test methods, such as [ASTM C666/C666M](#), [ASTM C672/C672M](#), and [ASTM C1262](#), are used to estimate the relative performances of concrete mixtures under accelerated F-T cycling. Be careful, however, interpreting the results from these tests. RCC specimens cut from pavements with proven good field performance have performed marginally when tested in the laboratory in accordance with [ASTM C666/C666M](#) and [ASTM C672/C672M](#). Note that sawed samples that expose the paste and aggregate system are not realistic in practice; the concrete skin protects the paste and aggregates from excessive damage. Any concrete subjected to such harsh, exposed testing conditions will show poor performance ([Portland Cement Association 2004](#)). In addition, ASTM C666/C666M requires the total saturation of specimens, which is unlikely for RCC pavements in the field.

According to laboratory test results and field evaluations, a better method for predicting field performance of RCC pavements may be [ASTM C1262](#) ([Luhr 2006](#)). Specimens taken from RCC pavement projects that performed poorly with ASTM C666/C666M and ASTM C672/C672M performed well when tested in accordance with ASTM C1262 ([Portland Cement Association 2004](#)).

When RCC is used in severe F-T conditions, consider the following practices:

- a) Use of sound, nondeleterious, durable aggregate
- b) Use of a dense, well-graded aggregate
- c) Use of an adequate quantity of portland cement and increased paste content. For example, [Luhr \(2006\)](#) found that RCC mixtures with total cementitious content of 500 lb/yd³ (300 kg/m³) had better F-T performance than those with 420 lb/yd³ (250 kg/m³)
- d) Compaction to at least 98 percent of the modified Proctor density
- e) Reduction of w/cm to less than 0.40
- f) Use of silica fume as a partial replacement for cement
- g) Use of air-entrainment additives when compatible with mixer
- h) Proper and timely curing

5.1.6 Shrinkage—Any significant change in volume experienced with RCC pavements is due to drying shrinkage. The volume change associated with drying shrinkage, however, is normally less than that in comparable conventional concrete mixtures due to the lower water content of RCC. The result is a lower volume of cement paste, which results in lower shrinkage and less cracking for RCC pavements. Research has also found that in a mixture with a constant cement amount, drying shrinkage decreases as the amount of coarse aggregate increases, due to high restraint offered by the aggregate particles ([Pittman and Ragan 1998](#)).

Thermal expansion and contraction properties of RCC are believed to be similar to those of conventional concrete made with similar materials.

5.1.7 Permeability—The permeability of RCC is largely dependent on voids in the compacted RCC, together with the porosity of the mortar matrix, and therefore is almost totally controlled by mixture proportioning, placement method, and degree of compaction. Hardened RCC permeability is comparable to that of conventional concrete.

5.2—RCC materials selection

RCC contains the same basic materials as conventional concrete—coarse and fine aggregates; cementitious materials, including cement, fly ash, and silica fume; water; and, when appropriate, chemical admixtures. Details about these constituents may be found in [Taylor et al. \(2006\)](#). The chemical admixtures, however, are used in different proportions. The cost of materials used in RCC is comparable to the cost of those used in conventional concrete. RCC typically has slightly lower cement content than conventional concrete of similar strength. The lower cement content can lead to some savings in material costs.

The correct selection of materials is essential to the production of quality RCC mixtures. Knowledge of mixture ingredients, along with construction requirements and specifications for the intended project, ensures the RCC mixture meets both design and performance objectives.

5.2.1 Aggregates—Mineral aggregates make up to 85 percent of the volume of RCC. They play an influential role in achieving the required workability, specified density in the field under vibratory compaction, compressive and flexural strengths, thermal properties, long-term performance, and durability.

Aggregates used in conventional concrete with a proven performance record should also work well in RCC. As with conventional concrete, the aggregate source should be inspected and tested for quality and consistency throughout the construction period. Testing can be performed to confirm the consistency of the aggregate gradation, as well as properties such as absorption, specific gravity, plasticity index, abrasion resistance, alkali-silica reactivity (ASR), and durability.

RCC differs from conventional concrete in its gradation requirements, which derive from the requirements of the RCC aggregate skeleton for compaction under compaction efforts from the paver and the steel drum and rubber-tired rollers. The fine and coarse aggregate gradation should be selected to ensure workability, compactibility, and surface finish.

Proper selection of aggregates and aggregate gradation for RCC pavements reduces the potential for segregation while improving its strength and durability. Aggregate selection will also affect both the water requirements and the amount of cementitious materials needed.

Practices for selecting and blending aggregates may vary depending on the local practices, construction specifications, severity of exposure, and availability of different sizes; the convenience to the concrete producer and contractor; and the economic environment. Crushed or uncrushed aggregates or blends may be used in RCC mixtures, depending on availability.

A dense, well-graded aggregate blend is most desirable. Aggregate suppliers may, in some cases, supply preblended product that meets the proper combined aggregate gradation. In most cases, this will be fine and coarse products that have been blended to produce the desired combined gradation. Figure 5.2.1 shows a suggested combined aggregate band, as well as gradation bands for a fine and coarse aggregate. Products falling within the fine and coarse bands may be blended at appropriate proportions to produce the desired combined gradation. Refer to Chapter 6 for more information on aggregate gradation.

The objective is to provide economical, strong, and long-lasting concrete. Refer to Chapter 6 for information on mixture proportioning. To achieve high-quality RCC, both the coarse and fine aggregates should be hard and durable. Standard physical property tests, such as those listed in ASTM C33/C33M, should be conducted to evaluate the quality of all aggregates used in the RCC mixture.

5.2.1.1 Coarse aggregates—Coarse aggregates meeting ASTM C33/C33M, AASHTO M6, and AASHTO M80 standards are recommended for RCC mixtures. Coarse aggregates are often limited to a nominal maximum size of aggregate (NMSA) of 3/4 in. (19.0 mm) to prevent segregation and achieve a tight surface. Typical NMSA varies from 5/8 to 3/4 in. (16.0 to 19.0 mm).

Those NMSAs that are larger than 3/4 in. (19.0 mm) and up to 1-1/2 in. (37.5 mm) can be used and, if properly proportioned with adequate fines, render a good quality finish. Larger NMSAs are typically used for nonwearing course or secondary applications where surface appearance is of little importance. Those NMSAs that range from 1/2 to 3/4 in. (12.5 to 19.0 mm) can be used to reduce segregation, enhance cohesiveness, provide a closed surface, and improve riding quality. A smaller NMSA, however, can increase the cement consumption and reduce the strength potential of the pavement. In addition to the routine lab testing of coarse aggregates, the Los Angeles abrasion test (ASTM C131/C131M; AASHTO T96) should be conducted. Some locations may also require testing for soundness (ASTM C88; AASHTO T104), ASR (ASTM C586; ASTM C1105; AASHTO T303), durability index (ASTM D3744/D3744M; AASHTO T103), and coefficient of thermal expansion (AASHTO T336).

5.2.1.2 Fine aggregates—Fine aggregates should meet the durability requirements specified in ASTM C33/C33M. The use of aggregate fractions finer than the No. 200 (75 μ m) sieve, if the fines are nonplastic, may help reduce fine aggregate voids in RCC mixtures. Nonplastic fines are material passing the No. 200 (75 μ m) sieve with low or no plasticity, as defined previously (Harrington et al. 2010).

The RCC aggregate skeleton to be consolidated under compaction efforts is significantly affected by the fine aggregates. A higher amount of fine aggregates allows for the reduction of cement and corresponding paste, which, when balanced by the proper gradation with coarse aggregate, provides for a compactable and durable mixture.

Angularity of the fine aggregates, although important in asphalt mixtures, is not a critical consideration in RCC mixtures. The workability and rutting resistance of asphalt

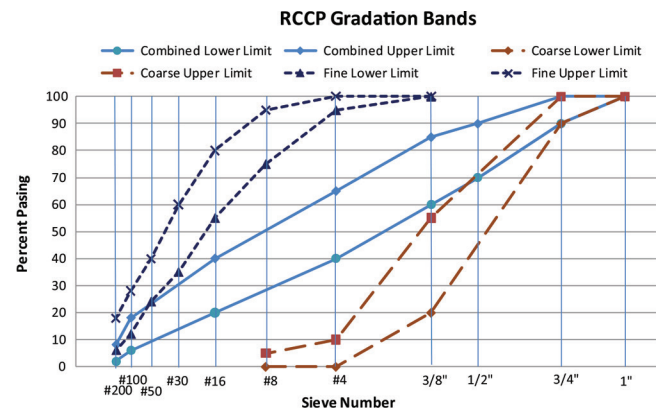


Fig. 5.2.1—Suggested combined aggregate grading with fine and coarse aggregate gradation bands (Harrington et al. 2010). (Note: 1 in. = 25 mm.)

mixtures, however, is highly influenced by the angularity of fine aggregates. Rutting resistance of asphalt pavements increases as the angularity of the fine aggregates in the mixture increases.

Compared to RCC, asphalt binder does not have the equivalent binder strength to hold aggregates together. The asphalt strength instead comes from the aggregate interlock that is dependent on the angularity of both coarse and fine aggregate. An asphalt pavement structure, therefore, can be constructed using thinner lifts than those required for RCC to achieve proper compaction.

Fine aggregates derived from natural sources are often abraded and thus rounded, resulting in relatively low angularity. These aggregate sources are therefore considered unsuitable for high-traffic volume asphalt applications, especially for surface or near-surface lifts.

In contrast, natural fine aggregates, which tend to be more rounded, are often used in RCC to form a strong matrix. As a result, naturally derived fine aggregate sources with a lack of angularity can be combined with properly graded coarse aggregate and a strong cement binder. The outcome is a single lift that can be up to 10 in. (254 mm) thick and still meet the required density.

The selection of fine aggregates is crucial because it determines the water requirement, which affects the cement consumption, compactability, surface smoothness, and durability of the RCC. River sand is a good source of concrete sand; however, manufactured sand is also widely accepted and used in RCC production. Screenings from crushed rock may also be used with care taken to ensure product consistency.

Silts and clays in RCC aggregates should be avoided because they can increase shrinkage and reduce strength. The plasticity index of the material passing the No. 40 (425 mm) sieve should not be higher than 4. Aggregate fines are typically in the range of 2 to 8 percent passing the No. 200 (75 μ m) sieve.

5.2.2 Cementitious materials—RCC mixtures can be made with basic hydraulic cements, blended cements, or a combination of hydraulic cement and pozzolan. A detailed