Roller-Compacted Concrete for Roadway, Industrial & Port Applications

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Concord, North Carolina

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Global Pavement Consultants, Inc.
Representing the National Concrete Pavement Technology Center
Guide for Roller-Compacted Concrete Pavements

• Available from the Portland Cement Association website www.cement.org/pavements.

• In 2011 training modules were developed under FHWA-NHI-131133

• The web based modules can be found on NHI’s website at: http://www.nhi.fhwa.dot.gov/default.aspx.
1. Key Elements of RCC
2. Common Uses
3. RCC Properties & Materials
4. RCC Mixture Proportioning
5. Structural Design
6. RCC Production
7. RCC Construction
8. Troubleshooting

APPENDIX:
• Design Examples
• Guide Specification for Construction of RCC Pavement
RCC Key Elements and Common Uses
What is Roller-Compacted Concrete (RCC) Pavement?

- Definition: “Roller-Compacted Concrete (RCC) is a no-slump concrete compacted by vibratory rollers”
- Materials are same as concrete—well-graded aggregates, cementitious materials, and water—but different mixture proportions
- Consolidated with paver and vibratory rollers
- After curing, RCC properties are similar to PCC

PCC  
RCC
What is Roller-Compacted Concrete (RCC) Pavement?

- Consistency is stiff enough to remain stable under vibratory rollers
- Wet enough to permit adequate mixing and distribution of paste
- Typically placed with asphalt-type paver equipped with standard or high-density screed
- Followed by a combination of passes with rollers for compaction
What is Roller-Compacted Concrete (RCC) Pavement?

- Final compaction is generally achieved within one hour of mixing.
- RCC pavements are constructed without forms, dowels, or reinforcing steel.
- Joint sawing is not always required, but when sawing is specified, transverse joints are spaced farther apart than with conventional concrete pavements.
RCC combines aspects of conventional concrete pavement with construction practices similar to HMA pavement.
Increased Use of RCC
History of Roller-Compacted Concrete

Timeline

1930s
1970s
Late 1980s-Early 1990s
1940s
Early 1980s
2000s
Typical aggregate gradation of RCC, depicted by the solid black lines, is similar to aggregate gradation of an intermediate asphalt layer, depicted by the dashed blue line.
The strength of RCC drops appreciably as its density drops.
Compaction

Conventional

High Density Paver

Roller
Basic Differences Between RCC and PCC

- Mix materials proportions
- Workability
- Paving
- Consolidation
- Finishing
- Hydration and curing
- Cracking, load transfer, and reinforcement
# Basic Differences Between RCC and PCC

## Mix materials proportions

<table>
<thead>
<tr>
<th>Conventional Concrete Pavements</th>
<th>RCC Pavements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aggregates typically account for 60 to 75 percent of the mixture by volume</td>
<td>Aggregates compose 75 to 85 percent of RCC mixtures by volume</td>
</tr>
<tr>
<td>w/cm ratio is typically 0.40 to 0.45</td>
<td>RCC mixtures are drier than conventional concrete due to their higher fines content and lower cement and water contents</td>
</tr>
</tbody>
</table>

## Workability

- Paving
- Consolidation
- Finishing
- Hydration and curing
- Cracking, load transfer, and reinforcement
### Basic Differences Between RCC and PCC

<table>
<thead>
<tr>
<th>Mix materials proportions</th>
</tr>
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<tbody>
<tr>
<td><strong>Workability</strong></td>
</tr>
<tr>
<td><strong>Conventional Concrete Pavements</strong></td>
</tr>
</tbody>
</table>
| • Manipulated by the paving machine (slump is generally about 2 in.) | • Consistency of damp aggregates  
|                            | • RCC's relatively dry and stiff mixture is not fluid enough to be manipulated by traditional concrete paving machines |

- **Paving**
- **Consolidation**
- **Finishing**
- **Hydration and curing**
- **Cracking, load transfer, and reinforcement**
# Basic Differences Between RCC and PCC

<table>
<thead>
<tr>
<th>Mix materials proportions</th>
<th>Workability</th>
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</table>

## Paving

<table>
<thead>
<tr>
<th>Conventional Concrete Pavements</th>
<th>RCC Pavements</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Mixture is placed ahead of a slipform paving machine, which then spreads, levels, consolidates through vibration</td>
<td>• Typically placed with a conventional or heavy-duty, self-propelled asphalt paving machine</td>
</tr>
</tbody>
</table>

## Consolidation

## Finishing

## Hydration and curing

## Cracking, load transfer, and reinforcement
Basic Differences Between RCC and PCC

**Mix materials proportions**

**Workability**

**Paving**

**Consolidation**

- **Conventional Concrete Pavements**
  - Consolidation occurs internally
  - Internal vibrators and surface vibrators on the paving machine fluidize the plastic concrete, releasing air

- **RCC Pavements**
  - Consolidation is typically accomplished externally by compaction of the concrete with pavers and rollers

**Finishing**

**Hydration and curing**

**Cracking, load transfer, and reinforcement**
# Basic Differences Between RCC and PCC

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<tr>
<td>Paving</td>
<td></td>
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<tr>
<td>Consolidation</td>
<td></td>
</tr>
</tbody>
</table>

## Finishing

<table>
<thead>
<tr>
<th>Conventional Concrete Pavements</th>
<th>RCC Pavements</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Conducted before initial set occurs</td>
<td>• Typically has an open texture (similar to HMA)</td>
</tr>
<tr>
<td>• Usually mechanically textured to improve friction</td>
<td>• Can be textured through diamond grinding</td>
</tr>
</tbody>
</table>

## Hydration and curing

## Cracking, load transfer, and reinforcement
Basic Differences Between RCC and PCC

Mix materials proportions

Workability

Paving

Consolidation

Finishing

Hydration and curing

Conventional Concrete Pavements

• Proper hydration and curing of the concrete pavement is critical to the long-term durability.

RCC Pavements

• Proper hydration and curing of the RCC mixture is critical to the long-term durability.

Cracking, load transfer, and reinforcement
## Basic Differences Between RCC and PCC

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<th>Paving</th>
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</table>

### Cracking, load transfer, and reinforcement

**Conventional Concrete Pavements**
- Load transfer is principally accomplished through dowel bars and tie bars
- Aggregate interlock assists with load transfer
- Location of cracks is controlled by cutting joints

**RCC Pavements**
- Joints usually not sawed in RCC industrial applications
- Fewer joints are sawed and they are spaced farther apart
- No dowel bars or tie bars are used
- Load transfer is accomplished through aggregate interlock
Basic Differences Between RCC and PCC

![Graph showing the percent total weight of different components in RCC and PCC.]

- **Cement + Flyash**: RCC is slightly higher than PCC.
- **Coarse Aggregate**: RCC is significantly higher than PCC.
- **Fine Aggregate**: RCC is significantly higher than PCC.
- **Water**: PCC is slightly higher than RCC.

![Images of PCC and RCC textures.]

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**PCC**

**RCC**
Basic Difference Between RCC & PCC

<table>
<thead>
<tr>
<th></th>
<th>Conventional PCC</th>
<th>Roller Compacted Concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>C.M.</td>
<td>11</td>
<td>10</td>
</tr>
<tr>
<td>Water</td>
<td>16</td>
<td>13</td>
</tr>
<tr>
<td>Air</td>
<td>6</td>
<td>1.5</td>
</tr>
<tr>
<td>Fine Agg.</td>
<td>26</td>
<td>35</td>
</tr>
<tr>
<td>Coarse Agg.</td>
<td>41</td>
<td>40.5</td>
</tr>
<tr>
<td>Percent by Volume</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>143 pcf</td>
<td>153 pcf</td>
</tr>
</tbody>
</table>

Comparison of aggregate distribution of conventional concrete (left) and roller compacted concrete (right) (photos courtesy of CTL Group)
Early Load Carrying Capacity of RCC and PCC

Conceptual illustration of the load carrying capacity of RCC and conventional concrete immediately following placement.

Suitable for occasional light traffic.
Early Load Carrying Capacity of RCC and PCC

Friction (Roller Compaction) + Cohesion (Hydration) = Total Load Carrying Capacity

Packing results in increased friction between particles that provide initial load carrying capacity with the help of the subgrade.

Hydration forms harder binder around aggregates to hold particles together.
Surface of RCC

- More of an open surface texture after rolling similar to an asphalt pavement surface
- Quiet pavement due to “negative texture”
- Can lose fine aggregate from their surface within two to four years service
  - Surface is treated by diamond grinding or an overlay when posted speeds exceed 30 mph
Benefits of RCC

• Primary benefit of RCC is that it can be constructed quickly and cost-effectively

• Savings associated with RCC primarily due to
  – Reduced cement content
  – Reduced forming and placement
  – Reduced construction times

• Can be designed to have high flexural, compressive, and shear strengths, which allow it to support heavy, repetitive loads

• RCC needs no forms or finishing

• No dowels, tie rods, or steel reinforcement
Benefits of RCC (cont.)

- Less concrete shrinkage and thus less cracking
- Low permeability
- Provides excellent durability and resistance to chemical attack, even under freeze-thaw conditions
- Eliminates rutting and subsequent repairs
Benefits of RCC (cont.)

- Provides enough structure capacity to allow early opening to light traffic
- RCC can be placed in lifts as thick as 10 inches
- Light-colored surface improves night vision
- RCC pavements have solar reflectance index (SRI) greater than 29
- Freeze-thaw durability of RCC is high even without the use of air entrainment.
Potential Limitations of RCC

- Diamond grinding or asphalt surfaced typically needed for speeds greater than 30 mph.

- Amount of RCC that can be mixed in a transit mixer or ready mix truck typically lower than amount for conventional concrete.

- Multiple horizontal lifts and adjacent slabs must be placed within an hour to ensure good bonding.
Pavement edges are more difficult to compact

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

Due to the dryness of the RCC mixture, admixture dosage requirements can be higher for RCC than for conventional concrete
Common Uses of RCC Pavements

- Ports/Heavy Industry
- Light Industry
- Airports
- Local Streets
- Arterial Streets
- Shoulders/Widening
- Base for Overlays
Sustainability

- Improved Fuel Economy
- Light Colored and Cool
- Less Fuel Consumed During Construction
- New Quiet Surface Textures
- Structural Capacity
- Lower Energy Footprint
- Industrial By-Product Use
- Renewal and Recycling
Ports/Heavy Industry

- Large, open areas with few obstructions that may delay the construction process, making them ideal candidates for RCC
- Pavement must be strong and durable because of heavy wheel loads
- In applications where the desired thickness is greater than 10 in. two lifts of RCC are required
Ports/Heavy Industry

- Type of Traffic
  - Heavy Port Equipment (up to 60 kips per tire are common)
- Design
  - USACE Method
  - RCCPave Program
- Surface Treatment
  - None for Speed < 30 mph
- Jointing
  - Typically None
  - Lane Traffic – Sawing done to improve load transfer
- Placement
  - High Density Paver
Airport Service (Storage/Parking Areas, or Base)

- RCC is commonly used for maintenance areas, parking lots, and snow storage areas.

- Pavement can withstand large loads such as heavy snow plowing and heavy truck traffic during snow events.

- RCC does not deteriorate under the saturated conditions caused by melting snow.
Airport Service (Storage/Parking Areas, or Base)

• Type of Traffic
  – Airplanes and Maintenance Equipment

• Design
  – RCCPave Program
  – USACE Method
  – AirPave
  – StreetPave
  – WinPAS
  – ACI 325.12R Table
  – ACI 330R-08 Table

• Surface Treatment
  – Diamond Grinding or Overlays May be Required in Areas with Airplane Traffic

• Jointing
  – Sometimes Required Except in Maintenance Areas
Light Industry and Access Roads

- Warehouse facilities and auto manufacturing facilities
- Traffic speeds typically are 30 mph or less
- Typical loadings are from semi-trucks
- Edge loading should be considered in the analysis
- Multiple lifts are seldom used
Light Industry and Access Roads

• Type of Traffic
  – High Volume of Trucks

• Design
  – StreetPave
  – WinPAS
  – RCCPave
  – USACE Method
  – ACI 325.12R Table
  – ACI 330R-08 Table

• Surface Treatment
  – None for Speed < 30 mph

• Jointing
  – Typically None
  – Lane Traffic – Jointing done to improve load transfer
Arterial Streets

• Maintaining traffic during construction is a major concern

• Traffic constraints and construction time is reduced using a single lift RCC pavement
Arterial Streets

• Type of Traffic
  – Buses, Passenger Cars
  – Trucks

• Design
  – StreetPave
  – WinPAS
  – ACI 325.12R Table

• Surface Treatment
  – Diamond Grinding
  – RCC Base with Overlay (High Speed Facilities)

• Jointing
  – Typically Required

• Placement
  – High Density Paver (for thicker pavements)
  – Conventional Paver
Local Streets and Roadways

• RCC for new residential developments

• Provides strong working platform during site-work and construction

• Surface treatments can be applied once the development nears completion
Local Streets and Roadways

- **Type of Traffic**
  - Passenger Cars
  - Delivery Trucks

- **Design**
  - StreetPave
  - WinPAS
  - ACI 325.12R Table

- **Surface Treatment**
  - Speeds > 30 mph surface smoothness important
  - Diamond grinding

- **Jointing**
  - To control random cracking
**Shoulders and Widening**

- Meets new lane and drop off criteria
- Strength and speed of construction make it suitable for road-widening applications
- Material provides a stable foundation
Shoulders and Widening

• Type of Traffic
  – Buses, Passenger Cars
  – Trucks

• Design
  – Thickness typically established by standards
  – For widening:
    – WinPAS
    – StreetPave
    – ACI 325.12R Table

• Surface Treatment for Widening
  – Rumble Strips
  – Diamond Grinding
  – Overlays

• Jointing
  – Match Existing Jointing
Multi-Layer Systems for High-Speed Roadways

- Can be used as a base under a thin asphalt wearing course for rideability
- Can be used as a base under unbounded conventional concrete overlay to reduce pavement thickness
- Allows for reduction in pavement thickness provides long term performance
- Provides an excellent construction platform

Example – Design a long-term pavement > 10 in. thick with a surface renewal limited to a 30 – 40 yr. cycle
  - Use a conventional concrete surface over an RCC pavement
  - System could be a wet-on-dry multi-lift system that would consist of an RCC base with a thin (4 in. to 6 in.) unbonded concrete overlay
  - Separation layer would be required
Multi-Layer Systems for High-Speed Roadways

• Type of Traffic
  – Highways: High-volume truck, bus

• Design
  – AASHTO Mechanistic-Empirical Pavement Design Guide (MEPDG)
  – StreetPave or WinPAS computer programs for mixed-vehicle traffic

• Surface Treatment (above interlayer)
  – Conventional concrete
  – Asphalt wearing course

• Typically RCC joints not sawed when an unbonded concrete overlay is used
Logging Facilities, Composting Areas, and Storage Yards

• Requires pavement strengths and durability to support the heavy loads

• Surface appearance, textures, and smoothness are less important for these applications

• Coarser aggregate can be used
Logging Facilities, Composting Areas, and Storage Yards

• Type of Traffic
  – Slow-speed heavy equipment

• Design
  – USACE method
  – RCC-PAVE

• Surface Treatment
  – Typically no surface treatment
  – Surface smoothness has an approximately ½ in. maximum variance for a 10 ft. straight edge

• Sawed Joints
  – None
Section 3

RCC PROPERTIES and MATERIALS
Section 5

STRUCTURAL DESIGN of RCC PAVEMENTS
RCC CONSTRUCTION
CONSTRUCTION TROUBLESHOOTING for RCC PAVEMENT
**Mixture consistency and setting**

- Mix too dry
- Fluctuations in workability

**Segregation**

- Segregation in paving hopper
- Mixture tends to segregate during paving and compacting
Compactibility/density

Honeycomb

Waviness from rolling

Required target density is not achieved

Edge slumping/poor consolidation at edge

Edge variation problems
<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Mixture consistency and setting</th>
<th>Segregation</th>
<th>Compaction/density</th>
<th>Surface appearance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Observed problem</strong></td>
<td>Mix looks dry</td>
<td>Early stiffening/settling or cemenston</td>
<td>Lack of stability of mix</td>
<td>Mixture looks sticky</td>
</tr>
<tr>
<td><strong>Materials</strong></td>
<td>Cement or SCM type</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>High cement/SCM content</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Low cement/SCM content</td>
<td>x</td>
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<td></td>
<td>Mix contains too few fines or binders (cement/SCMs)</td>
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<tr>
<td></td>
<td>Sand is too fine or mix is too sandy</td>
<td>x</td>
<td>x</td>
<td></td>
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<tr>
<td></td>
<td>Quality/quantity of fine aggregates</td>
<td>x</td>
<td>x</td>
<td></td>
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<tr>
<td></td>
<td>Angularity of aggregates</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Inconsistent aggregate gradation or changes in gradation</td>
<td>x</td>
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<td></td>
<td>Moisture changes in aggregates</td>
<td>x</td>
<td>x</td>
<td></td>
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<tr>
<td></td>
<td>Mix contains excess water</td>
<td>x</td>
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<tr>
<td></td>
<td>Mix contains insufficient water</td>
<td>x</td>
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<tr>
<td></td>
<td>Chemical admixture overdose, underdosing, and/or incompatibility</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td><strong>Storage, batching, and mixing</strong></td>
<td>Excess material temperature, especially aggregates</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Incomplete mixing</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<td></td>
<td>Plant is out of calibration</td>
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<td></td>
<td>Load cells or moisture sensors are not functioning</td>
<td>x</td>
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<tr>
<td></td>
<td>Moisture losses are not accounted during batching</td>
<td>x</td>
<td></td>
<td></td>
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<tr>
<td><strong>Transportation</strong></td>
<td>Evaporation water losses</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>RCC is transported without any covering</td>
<td>x</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Extended load time from mixing to placement</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<tr>
<td></td>
<td>Dump trucks not covered</td>
<td>x</td>
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<tr>
<td></td>
<td>Dump trucks not washed periodically</td>
<td>x</td>
<td></td>
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<tr>
<td><strong>Paving</strong></td>
<td>Paving speed is faster than recommended</td>
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<tr>
<td></td>
<td>Paving speed is slower than recommended</td>
<td>x</td>
<td>x</td>
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<tr>
<td></td>
<td>Served configuration, age, load, wear, etc.</td>
<td></td>
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<tr>
<td></td>
<td>Problems with mixing auger</td>
<td></td>
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<tr>
<td><strong>Compaction</strong></td>
<td>Vibration is applied too early</td>
<td></td>
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<td></td>
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<tr>
<td></td>
<td>Viable compaction speed</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Insufficient compaction effort</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Compaction is delayed</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Mix is not ready for compaction</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Others</strong></td>
<td>Poor quality or poor coverage of curing compound</td>
<td></td>
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<tr>
<td></td>
<td>Delay in the application of curing compound</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Delayed saw cutting</td>
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</tbody>
</table>
THANK YOU!

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