Atkinson Blvd – Roseville, CA

RCC PAVEMENT FOR LOWER VOLUME ROADS

ILLINOIS TRANSPORTATION AND HIGHWAY ENGINEERING CONFERENCE 2019

Corey J. Zollinger, P.E.

CEMEX

RCC Pavement Council


Hickory Street– Roseville, CA

KEY QUESTIONS TO BE ANSWERED TODAY

- What is Roller Compacted Concrete?
- Where has it Been Used?
- Why is it a Great Solution for Lower Volume, Local Roads?
- What are the Key Aspects to the RCC Construction Process?
- How does RCC Perform over the Long Term?

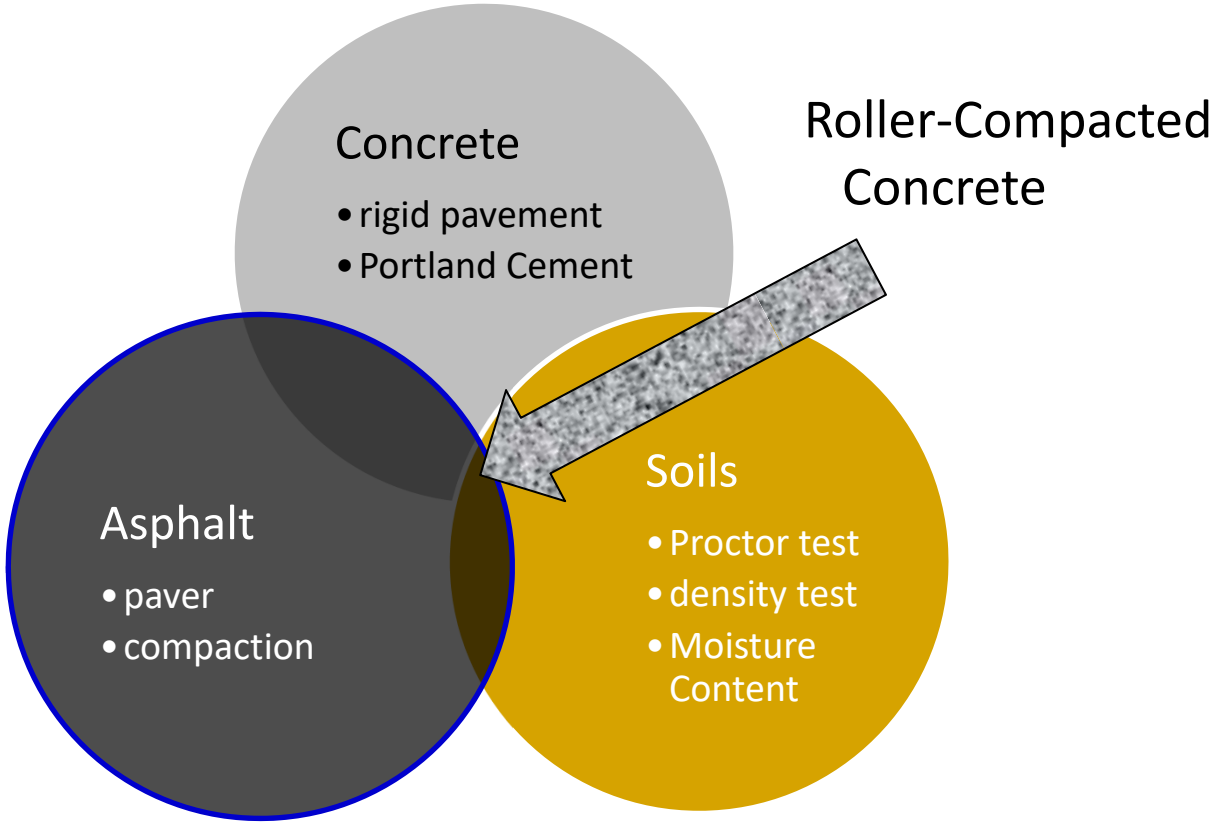
ROLLER COMPACTED CONCRETE IS A NEGATIVE SLUMP CONCRETE

A negative-slump concrete that is compacted not consolidated.

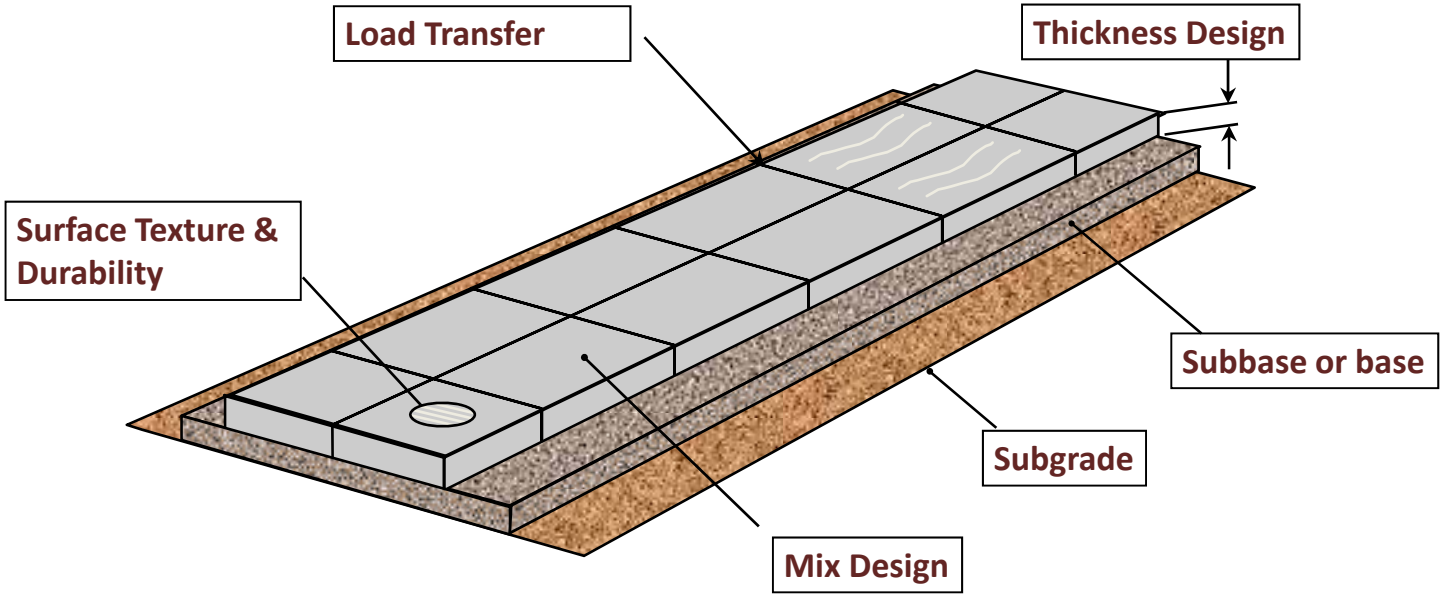
- Placed with High Density Asphalt Machine
- No forms
- No reinforcing steel, dowels, or fibers (Changing…)
- No finishing. (Changing…)
- Compacted with rollers (Changing…)
- No internal vibration (consistency of damp gravel).

RCC is a concrete pavement that is placed in a different way!

MULTIPLE PERSONALITIES



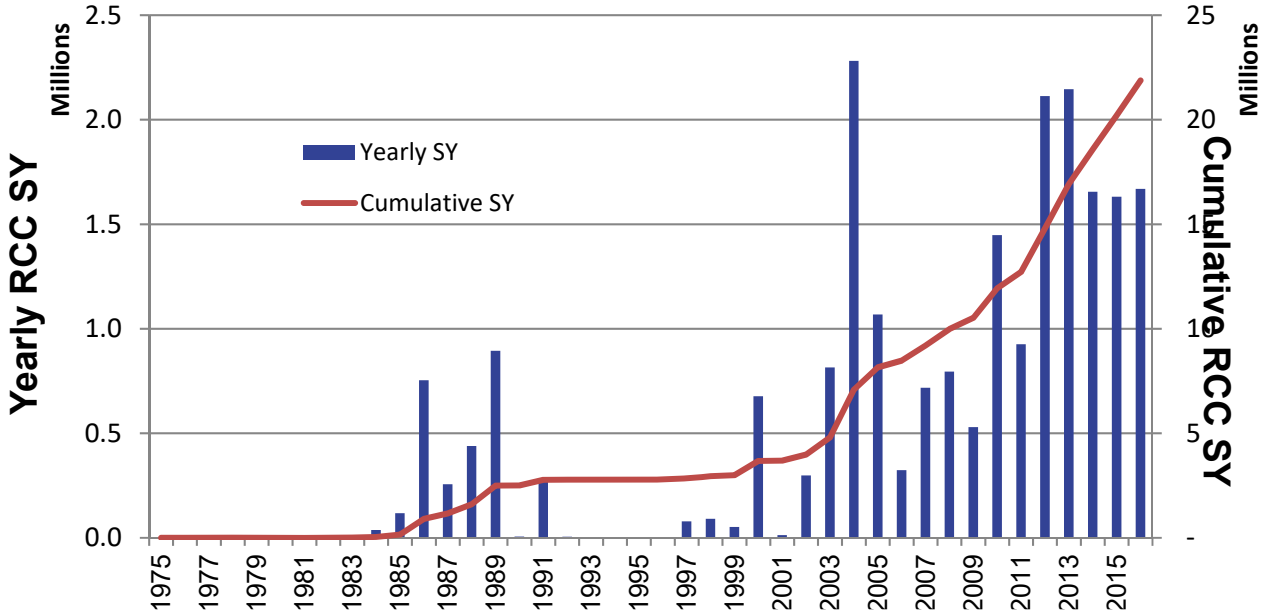
RCC DESIGN FEATURES



USE OF RCC PAVEMENTS IN US

RCC utilization began in the 80's, started growing in early 2000's & is now exploding

RCC SY PAVED BY YEAR



	1975 – 1999	2000-2010	2011-2013	2014-2016
# of Projects	71	101	197	226
SY	2,999,771	8,933,250	4,993,296	4,955,036

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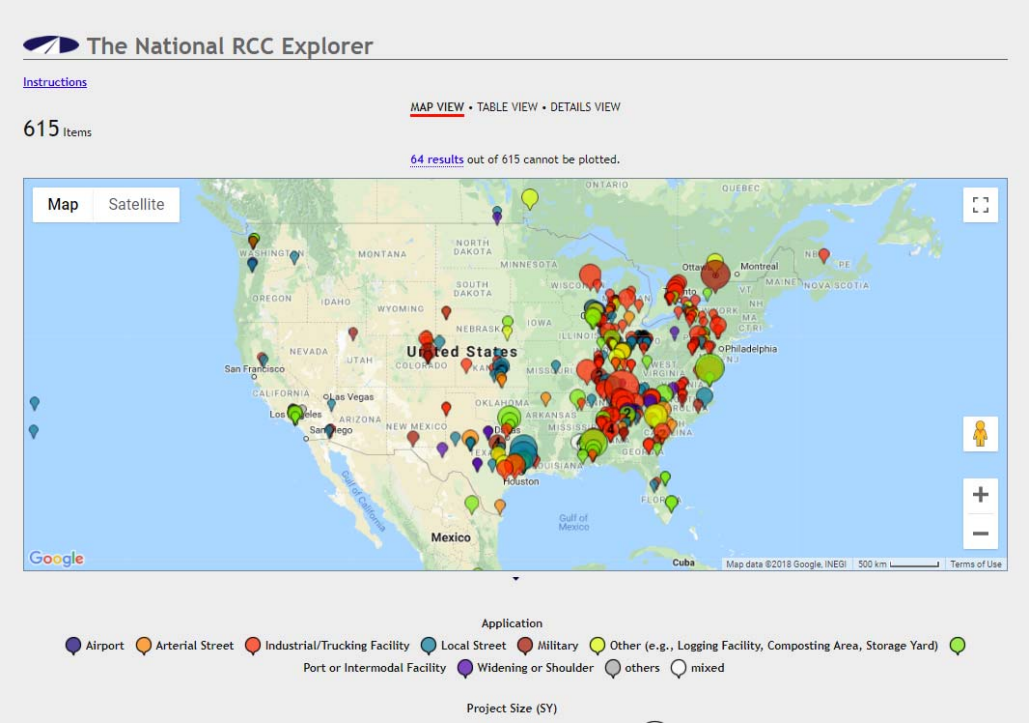
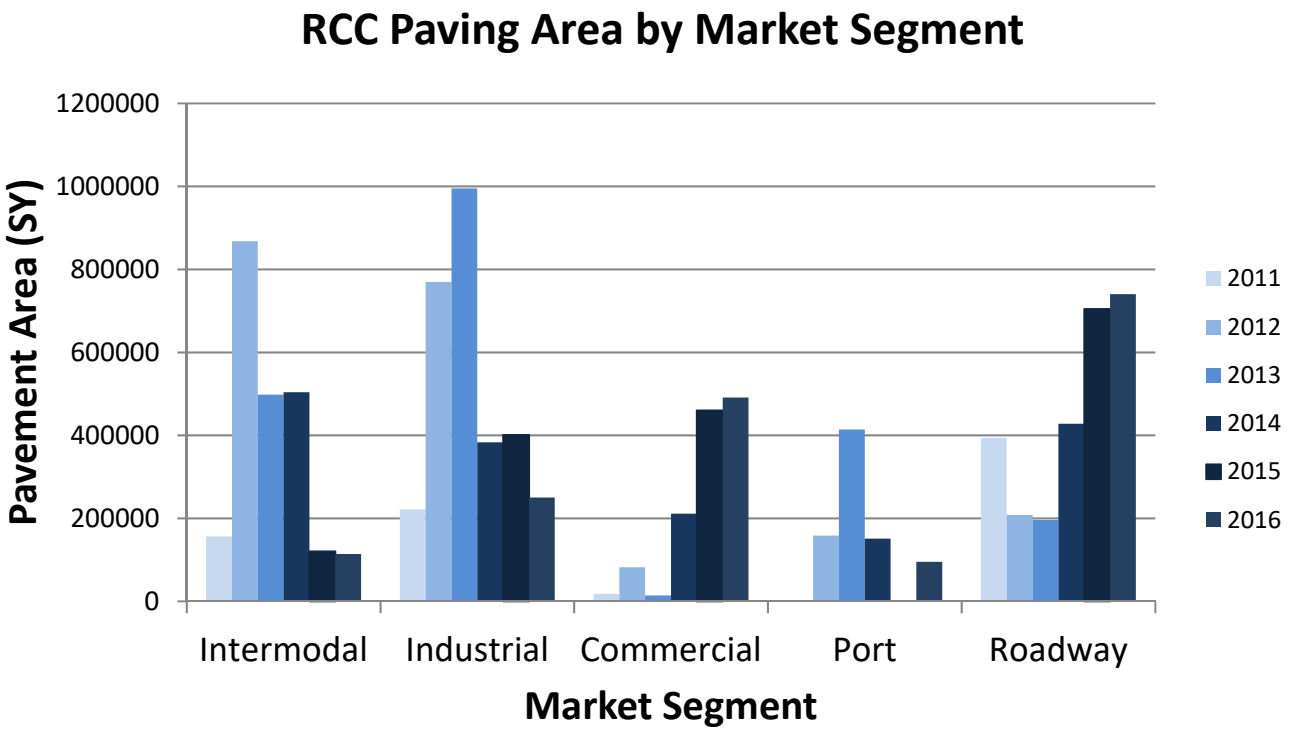


Reasons for Growth:

- Fast installation
- Low initial cost
- Durable
- Ease of placement in Urban areas
- Dedicated business development and promotion people

	1975 – 1999	2000-2010	2011-2013	2014-2016
# of Projects	71	101	197	226
SY	2,999,771	8,933,250	4,993,296	4,955,036

RCC IS BEING USED IN NEARLY ALL PAVEMENT APPLICATIONS

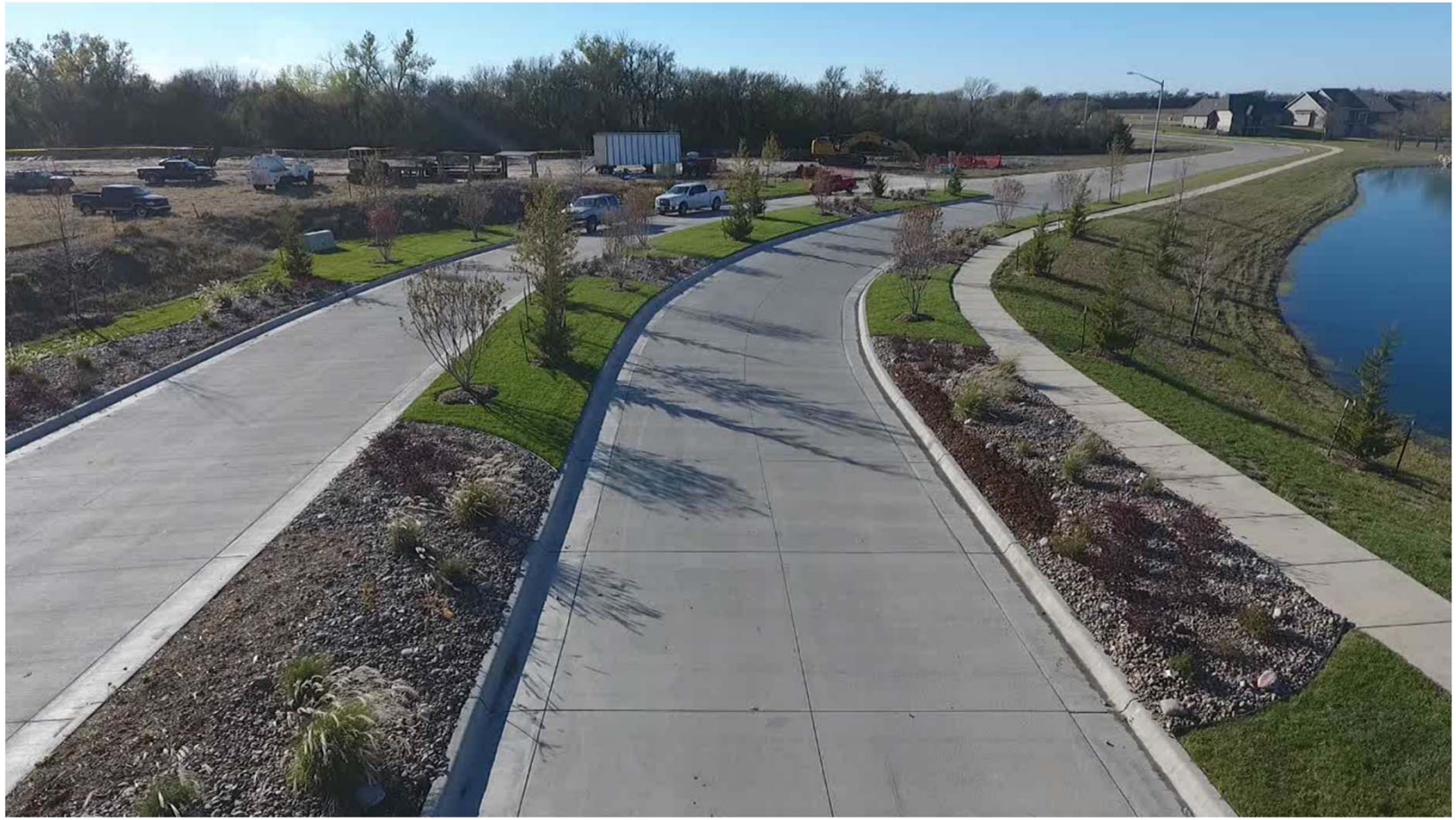


COLONY RIDGE DEVELOPMENT
Liberty County, TX

Type	Asphalt	RCC
Local/ Collector	2” HMAC 7” Flex Base 6” Stab Sub	6” RCC 6” Stab Sub
Arterials	2” HMAC 9” Flex Base 6” Stab Sub	7” RCC 6” Stab Sub

- RCC Thickness: 5”
- Cement Stabilized Subgrade: 6”
- Size: 70 miles of neighborhood streets.
- Width: 22-foot-wide

CHAPELS LANDING – Wichita, KS



Grape Creek Road – San Angelo, TX - 2011

Lake View Heroes– San Angelo, TX - 2012


LAMESA DRIVE
MIDLAND, TX - 2014
VOGELE
WACKER

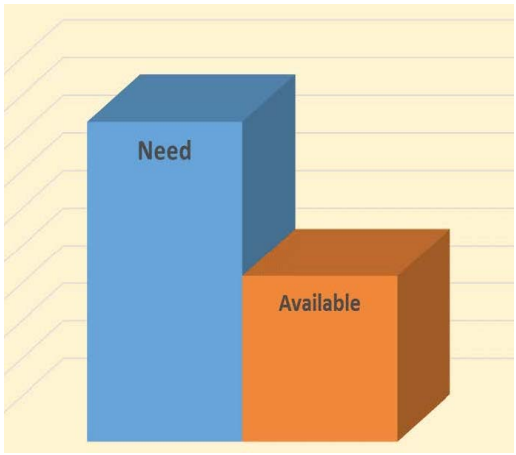
HIGHWAY APPLICATIONS ARE ALSO COMMON

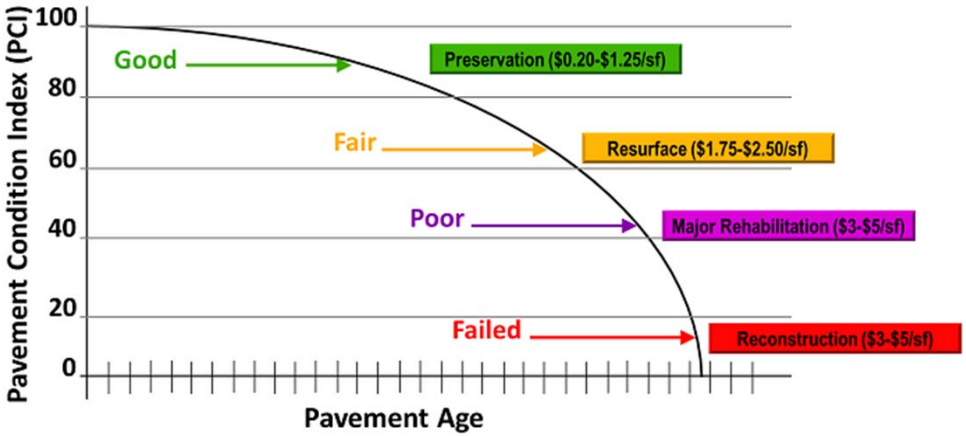
I 85 Shoulder – Greensboro, NC – 2017 / 2018

RICHLAND AV. (US 78) AIKEN, SC - 2008

City of Roseville, CA Challenge

Maintenance Funding





- **Roseville – 1,000 lane miles of asphalt roadway**
- **Need to maintain 100 lane miles/year – $8.5 million**
- **City averages $4.4 million/year available for roadway maintenance - about half of what is needed**

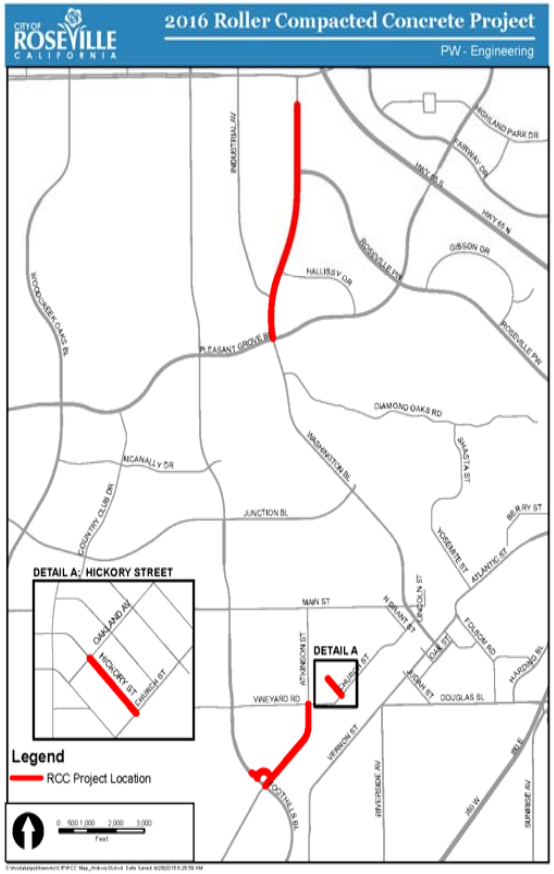
ROSEVILLE DECIDED TO BUILD A PILOT PROJECT

Complete reconstruction of three sections of failed road

- Washington
- Atkinson
- Hickory

- Three differing road types – arterial, collector, residential

- Three different finishes – natural, diamond grind, troweled



CITY OF ROSEVILLE, CA RCC - 2018

Atkinson Blvd
8.5” RCC / 4” Agg. Base

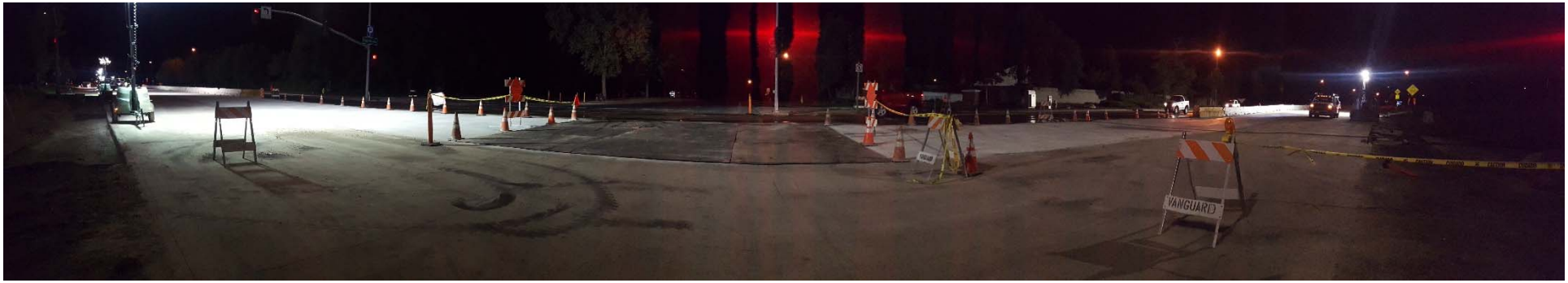
Washington Blvd
7” RCC / 6” Stab. SG

Hickory Street
5” RCC / Compacted SG

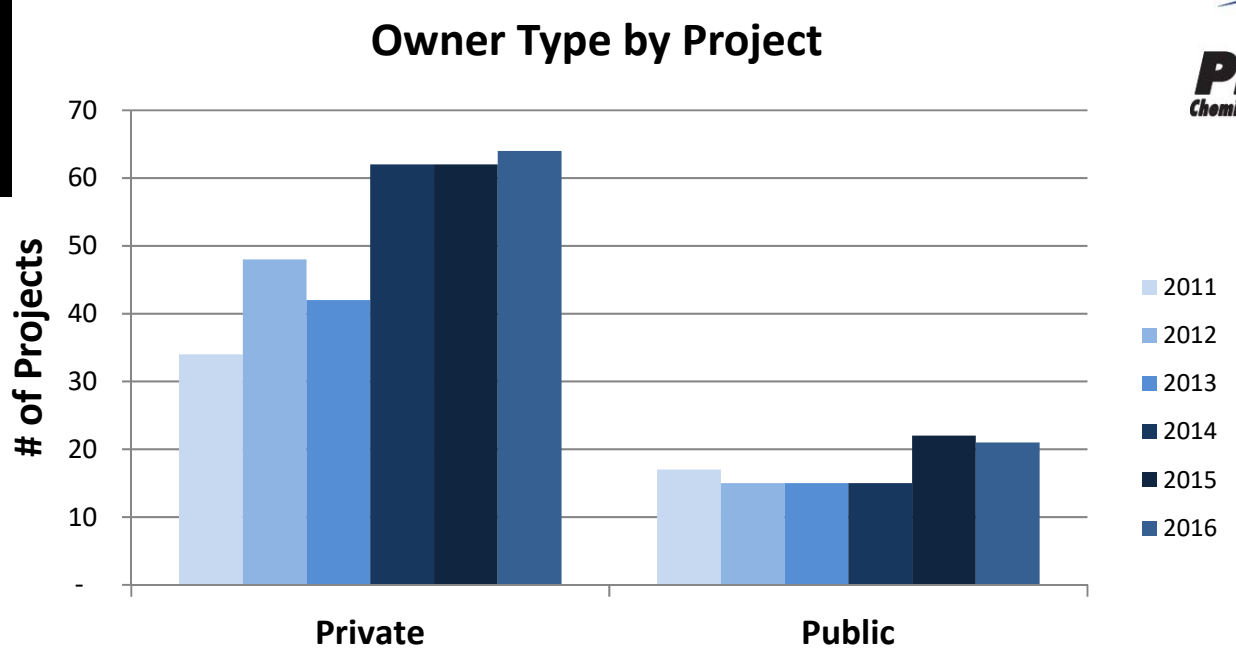
WHAT ARE THE KEY BENEFITS OF RCC FOR LOWER VOLUME ROADS?

Benefits of Building Concrete / RCC Pavements

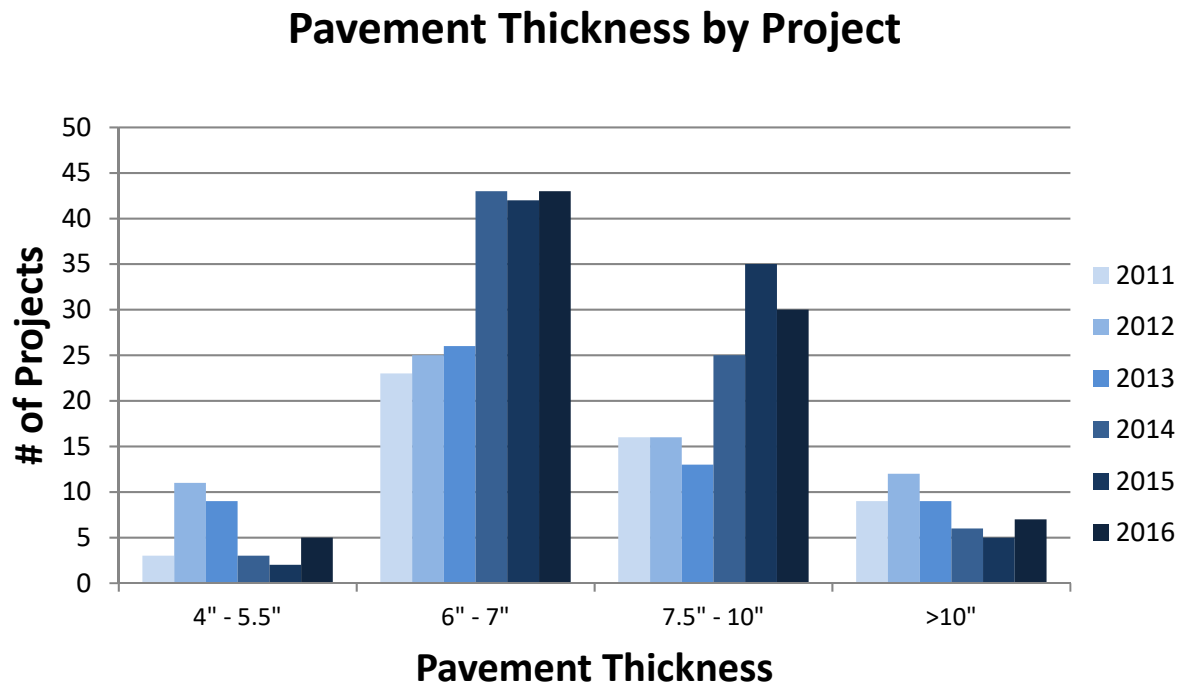
1. Stimulation of competition
2. Reduced Maintenance Cost
3. Free up budget for other roads
4. Fast Construction process
5. Early Open to Traffic
6. Driveways open to Traffic within Hours
7. Ease of placement in Urban Environment



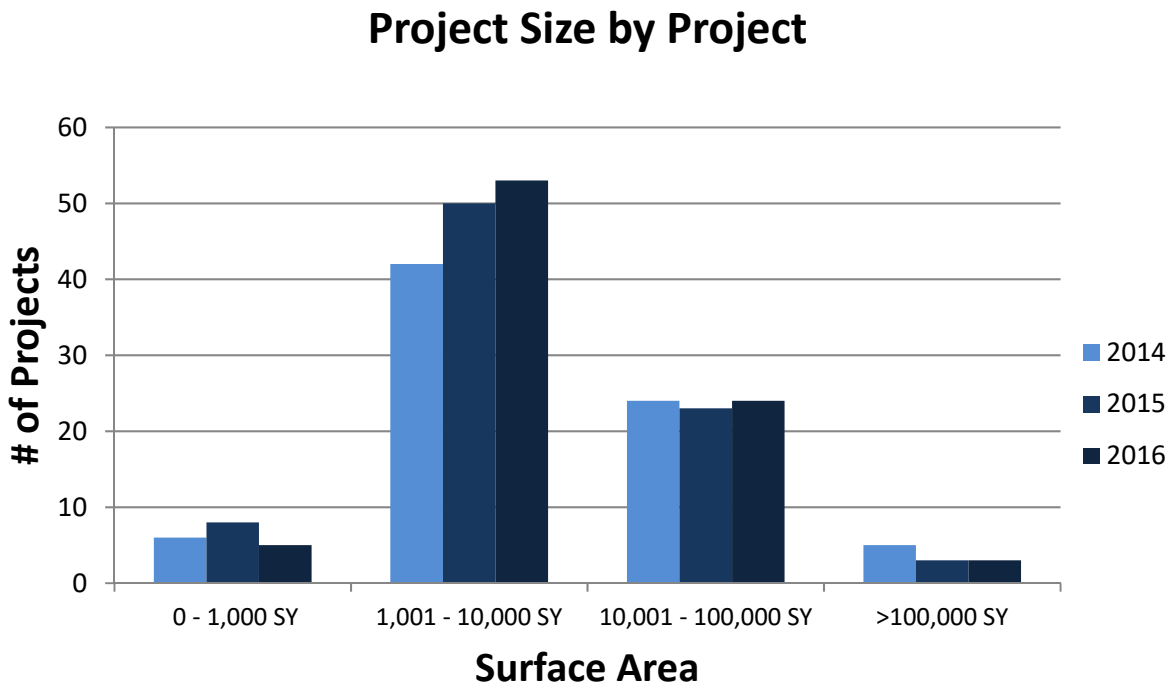
PRIVATE INDUSTRY CONTINUES TO LEAD IN RCC PAVEMENT USE



PAVEMENT THICKNESSES ARE TYPICAL FOR CONCRETE PAVING

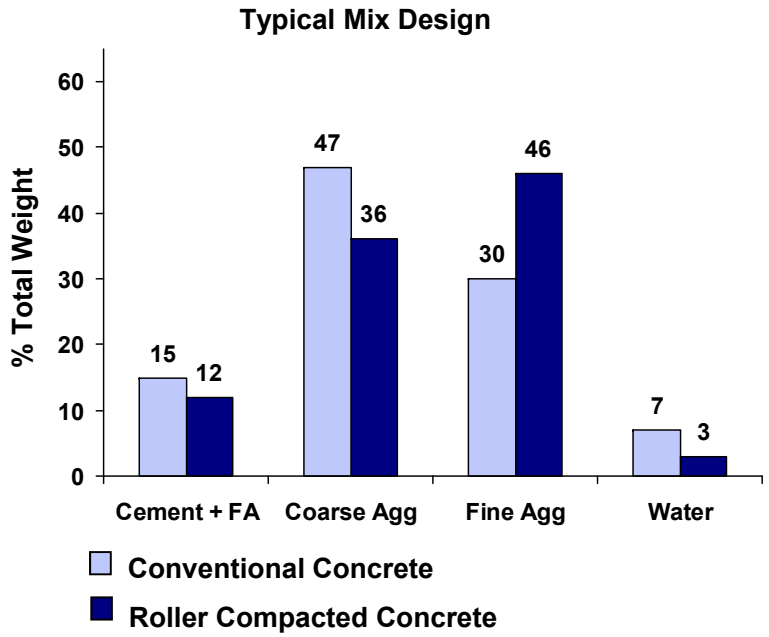


PROJECTS TEND TO RANGE FROM 1,000 TO 100,00 SY



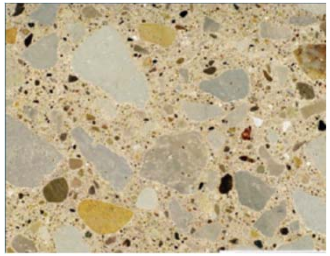
RCC MIX DESIGN USES SAME MATERIALS AS CONVENTIONAL CONCRETE, HOWEVER IN DIFFERENT COMBINATIONS

Achieves Similar or Better Engineering Properties Than Conventional Concrete



Typical Engineering Properties	Conventional (psi)	RCC (psi)
Compressive Strength	3,000 - 5,000	4,000 - 6,000
Flexural Strength (MOR)	500 – 700	600 - 850
Elastic Modulus	3.0 – 5.0 million	3.0 – 5.5 million

Conventional Concrete



RCC

IMPROVED UNDERSTANDING OF "AGGREGATE SELECTION" AFFECT ON "COMPACTED BEHAVIOR"

Many Projects are Achieving >98% Density Behind Paver

Aggregate Properties

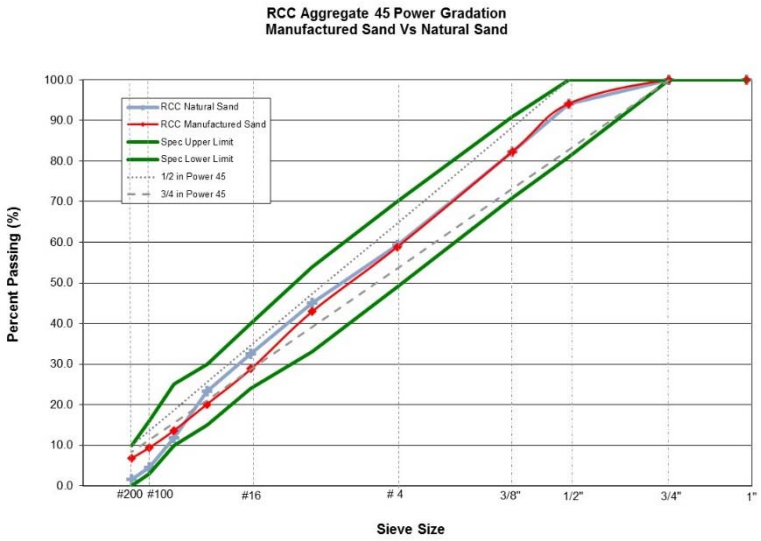
- Size Distribution
- Sand Type
- Aggregate Shape
- Top Size
- Absorption

Compacted Behavior

- Screed Stability
- Cold Joint Forming
- Surface Appearance
- Strength
- Roller Marks
- Density
- Segregation
- Ideal Moisture Content

HOW DOES SAND TYPE AFFECT THE PAVING MIX?

Example from California Project



Mix Design	Mix #1 (Man Sand)	Mix #2 (Conc Sand)
½" X #8 Crushed Aggregate. (%)	20	20
⅜" X ¼" Crushed Aggregate. (%)	25	25
Manufactured Sand (%)	55	
Concrete Sand (%)		55
Proctor Metrics		
Maximum Dry Density (pcf)	141.7	145.0
Optimum Moisture Content (%)	5.7	5.4

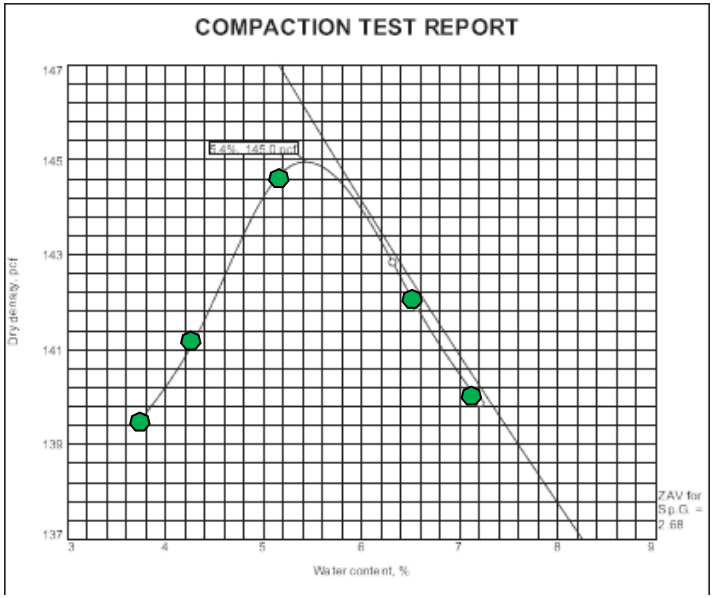
MIXTURE DESIGN PROCEDURE

Step 2: Select a mid – range cementitious content

- **Minimum 450 lbs cement / CY**
- **12% Type I Portland cement is selected for the first trial batch**
- **Based % on weight, so make enough and do not worry about volumes yet**
- **Mix the cement dry, and then add water**

(ASTM D1557)

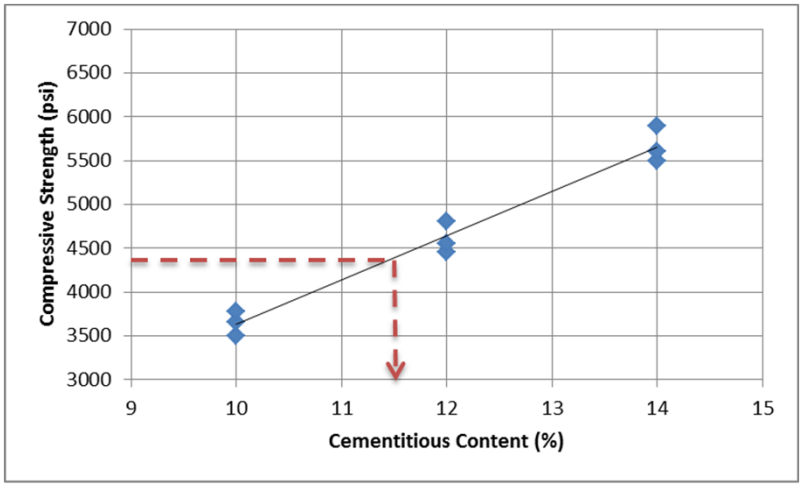
- ***Step 3: Develop moisture – density relationship plots***
- **Perform a modified Proctor test at the selected cement content**
- **Construct moisture-density relationship curve (Use spreadsheet)**
- **Determine Maximum Dry Density (MDD) and Optimum Moisture Content (OMC)**



MIXTURE DESIGN PROCEDURE

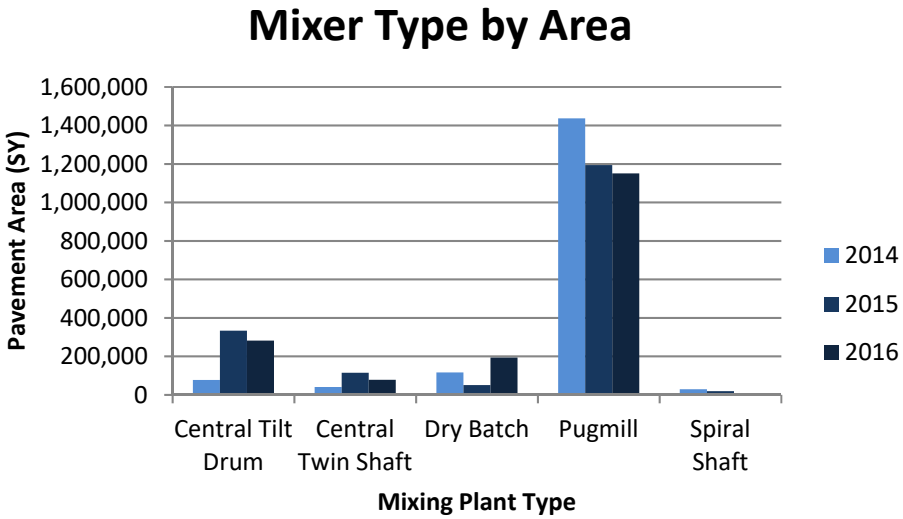
Step 4: Cast samples to measure compressive strength (ASTM C 1435)

- **Calculate trial mix proportions**
- **Batch RCC materials**
  - **Maintain percent Optimum Moisture Content as determined in step 3**
  - **Use varying cementitious contents such as 10, 12 and 14 percent**
- **Make compressive strength test cylinders for each cement content**



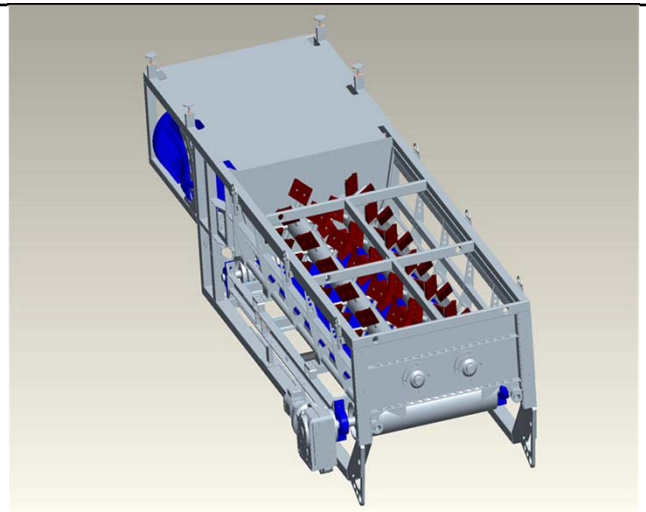
PUGMILL PLANT IS THE TYPICAL PRODUCTION PLANT TYPE

However, Other Plant Types Are Used On Smaller Projects



WE RECOMMEND USING A PUGMILL MIXER DUE TO HIGH PRODUCTION RATES & EFFICIENT MIXING PROCESS

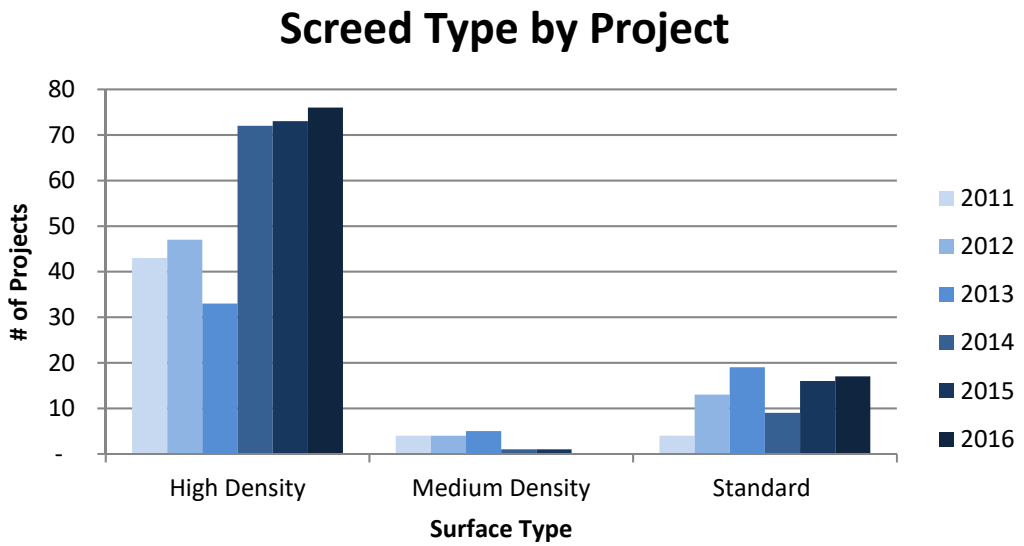
Factors to Consider
• High production rates: 50 to 300+CY / hr
• Excellent mixing efficiency for dry materials
• Highly consistent mix properties,
• Mobile – 1 load, 1 Day Set up and calibration
• Need to find good location, obtain permits
• Self contained – Gen set, batch house
• 2 to 3 man operation
• # of Aggregates depends on Feeder system



CONTINUOUS RCC MIXING PLANT (PUGMILL) IN ACTION

HIGH DENSITY SCREEDS ARE MOST EFFECTIVE PAVER TYPE

However, Standard Screeds Are Used On Smaller Projects



RCC IS PLACED WITH HIGH DENSITY ASPHALT PAVERS
Achieving Density & Smoothness is Critical

ROLLERS ARE USED TO ACHIEVE DENSITY AND PROVIDE FINISH

Initial Compaction

- Initial: 10 - 12 ton static & vibratory roller
- Establish roll pattern (check density a lot!)
- Adjust roll pattern based on moisture content
- Compact to 98% density - wet
- Adjust moisture content if needed – impacts smoothness & compaction
- Finer mixes achieve density easier

Finish Rolling

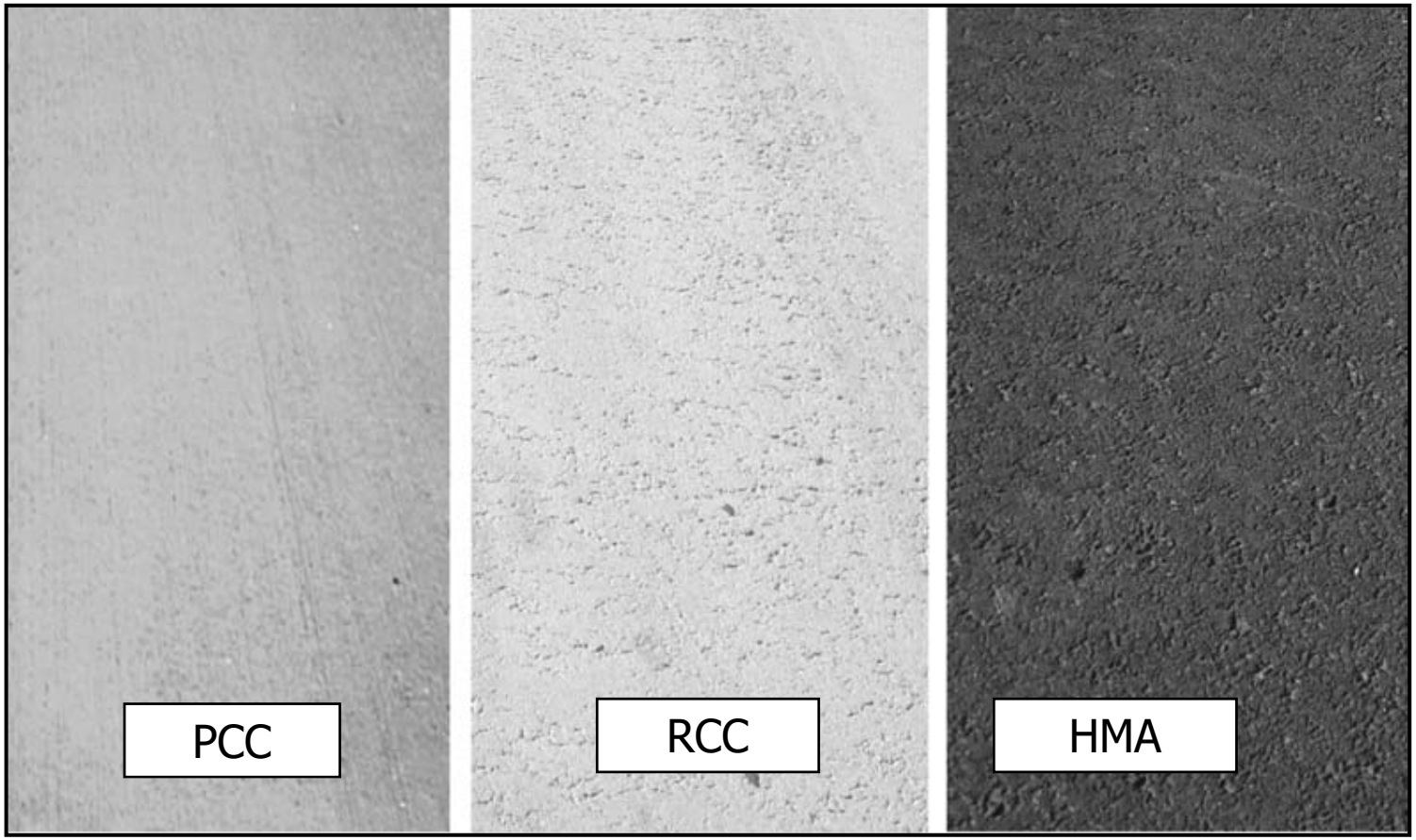
- Combination, dual steel or rubber tired
  - Maximum weight - 6 short ton
- Remove roller marks
- Once completed, keep roller off of the area

Grape Creek Road – San Angelo, TX

Fairforest Way
Greenville, SC

Fairforest Way
Greenville, SC

THE SURFACE APPEARANCE AND TEXTURE OF RCC IS SIMILAR TO ASPHALT PAVEMENT

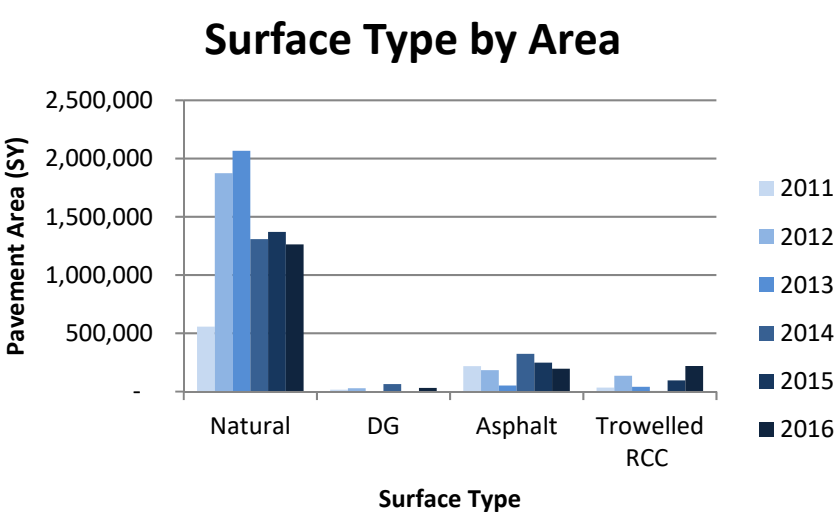


THE FINAL SURFACE TYPE WILL DICTATE THE NECESSARY TECHNIQUES & EQUIPMENT NEEDED TO BE SUCCESSFUL

	Natural RCC	Diamond Ground RCC	Asphalt
			
Applications	• Ports • Distribution centers • Industrial yards • Residential roads • Parking lots	• Collector / Arterial local roads • Highway Shoulders • State routes	• Any pavement type
Factors	• Lowest Cost • Most sensitive to contractor skill level • Least smooth • “Asphalt” appearance	• Medium cost increase • Increased construction time • Improved smoothness, skid resistance • Reduced noise	• Highest cost • Increased construction time • Least sensitive to contractor skill level • Improved smoothness, skid resistance

NATURAL SURFACE IS MOST COMMON,

However, Trowelled & or Broom Surfaces Are Increasing in Use



QC / QA PROCESS INCLUDES TESTING FOR DENSITY, MOISTURE CONTENT & COMPRESSIVE STRENGTH

Moisture & Density

- Tested with nuclear gage in direct mode
- Test density behind paver & after roller to establish rolling patterns to achieve density
- Achieve 98% of modified proctor wet density
- Nuclear gage gives general moisture fluctuation indication - Calibrate with oven dried moisture
- Oven dried is most accurate

Compressive Strength

- Cylinders prepared with vibratory hammer according to ASTM C1435
  - 3 to 4 cylinders per set
  - Strength timing often depends on traffic opening (1, 3, 7, 28 days)
- Cores can be obtained where density is not being achieved

WHEN CURED & SAW CUT RCC PERFORMANCE IMPROVES

Curing

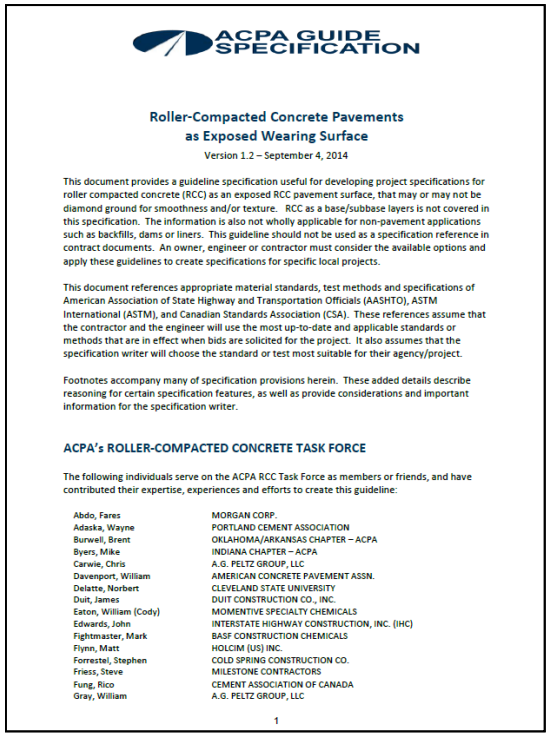
- Applied at 150 SF/ Gallon or better
- Ensure uniformity with application process
- Apply as soon as possible behind roller operation
- Recommend High Quality Curing Compound
- Ensures durable surface

Saw Cut & Fill Joints

- More aesthetically pleasing
- Early entry saw very effective, shortly following placement
- Recommend sawing within 2 - 6 hours to avoid uncontrolled cracking
- Depth: ¼ depth
- Spacing: Maximum 24 times thickness max 15 ft

TECHNICAL RESOURCES HAVE BEEN DEVELOPED

Construction Specifications are available



ACPA GUIDE SPECIFICATION

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:

Abdo, Fares	MORGAN CORP.
Adaska, Wayne	PORTLAND CEMENT ASSOCIATION
Burwell, Brent	OKLAHOMA/ARKANSAS CHAPTER – ACPA
Byers, Mike	INDIANA CHAPTER – ACPA
Carwie, Chris	A.G. PELTZ GROUP, LLC
Davenport, William	AMERICAN CONCRETE PAVEMENT ASSN.
Delatte, Norbert	CLEVELAND STATE UNIVERSITY
Duit, James	DUIT CONSTRUCTION CO., INC.
Eaton, William (Cody)	MOMENTIVE SPECIALTY CHEMICALS
Edwards, John	INTERSTATE HIGHWAY CONSTRUCTION, INC. (IHC)
Fightmaster, Mark	BASF CONSTRUCTION CHEMICALS
Flynn, Matt	HOLCIM (US) INC.
Forrestel, Stephen	COLD SPRING CONSTRUCTION CO.
Friess, Steve	MILESTONE CONTRACTORS
Fung, Rico	CEMENT ASSOCIATION OF CANADA
Gray, William	A.G. PELTZ GROUP, LLC

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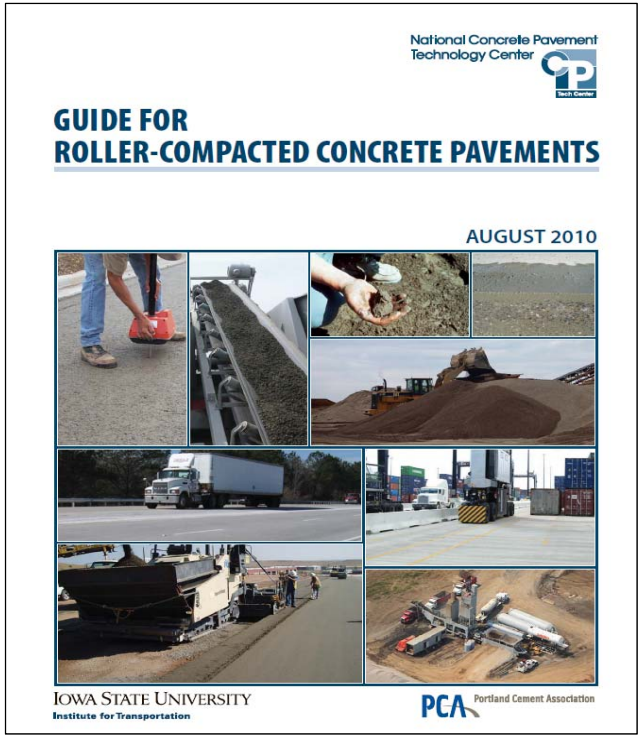
Guideline specification for Exposed Surface RCC pavements



National Concrete Pavement Technology Center

GUIDE FOR ROLLER-COMPACTED CONCRETE PAVEMENTS

AUGUST 2010

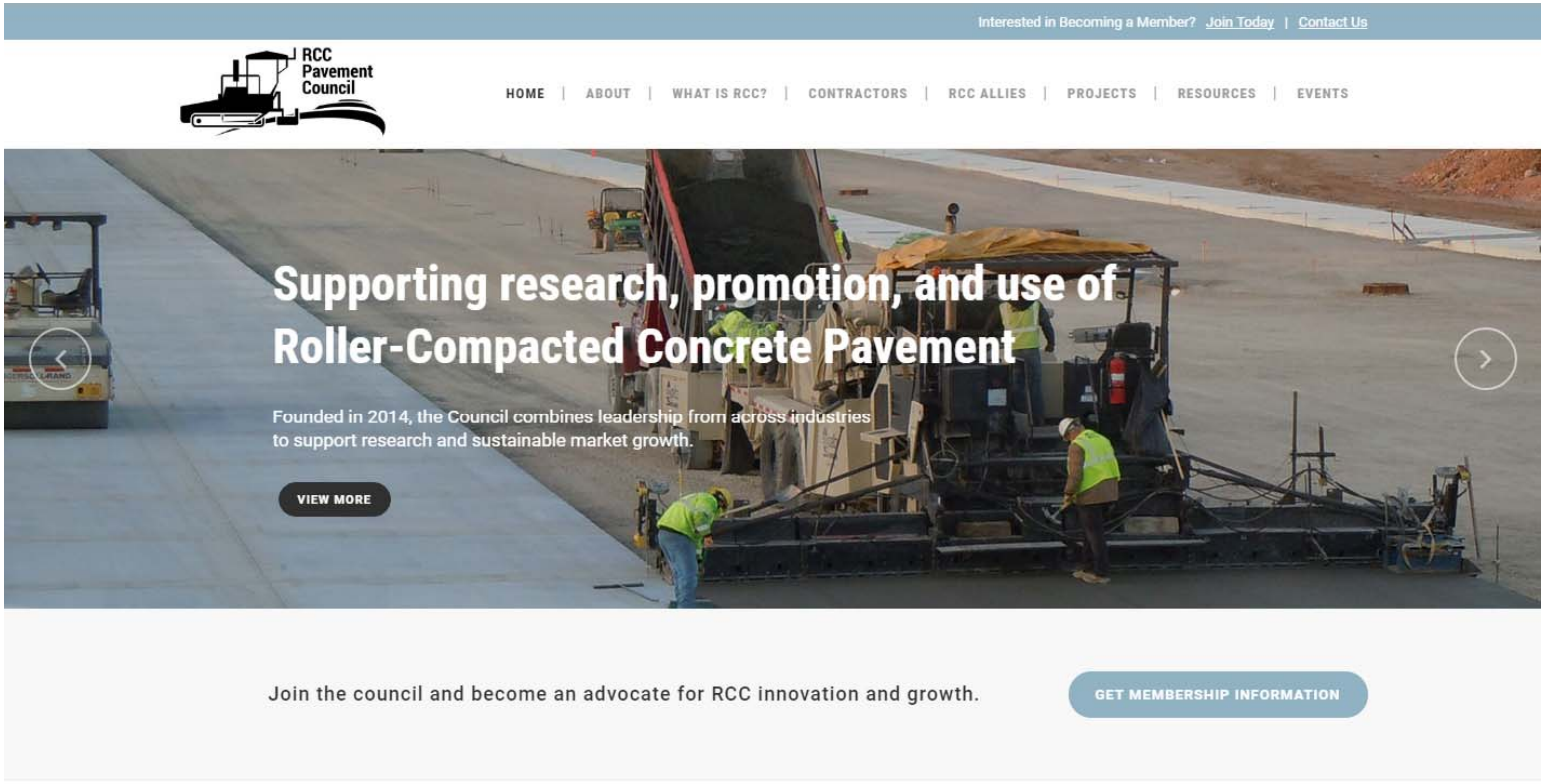
IOWA STATE UNIVERSITY Institute for Transportation

PCA Portland Cement Association

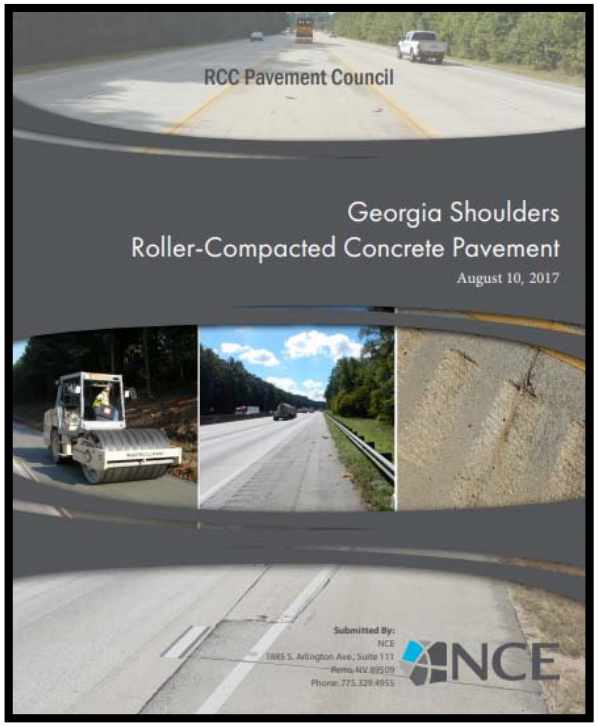
- **Developed by the CPTech Center at Iowa State**
- **Covers all aspects**
- **Available through PCA**

RCC PAVEMENT COUNCIL WAS FOUNDED IN 2014

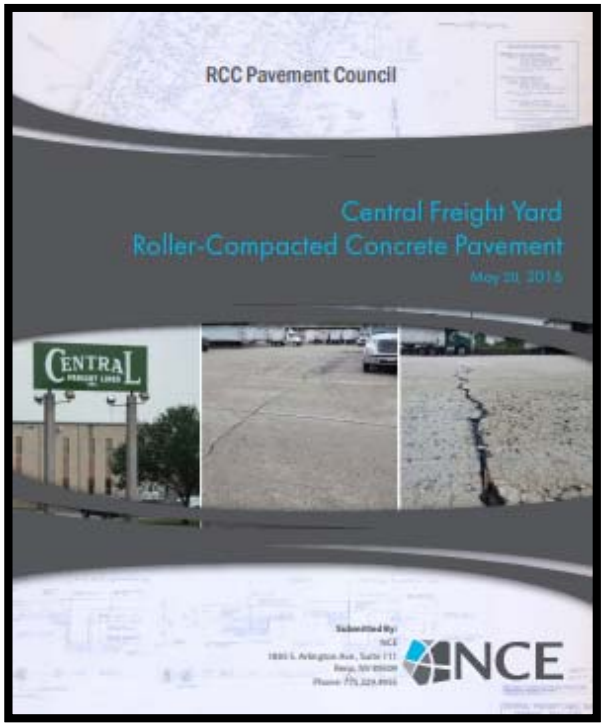
Provides Support for Research and Promotion



RCC PAVEMENT COUNCIL PROVIDES CASE STUDIES ON LONG LIFE RCC PAVEMENTS



- Starting in 2004, the Georgia DOT (GDOT)
- 17.3 mile stretch of I-285 between I-85
- To date, no maintenance has been done.



- Location - Austin, Texas
- Pavement Area - 14.5 Acres
- RCC Thickness - 7-8 inches
- Initial Construction - 1987.

- Location - Denver, CO
- Pavement Area - 28
- RCC Thickness - 15-20 inches
- Initial Construction - 1986

CEMEX

FUTURE OF RCC?

Bonded or Unbonded Overlays

Trowelled / Broom Surface

Fiber Reinforced RCC

SOME FACTORS TO CONSIDER WHEN BIDDING PROJECTS

- Volume of RCC paving on the project
- Site geometry
- Project phasing
- Pavement thickness
- Pavement width
- Final surface characteristics
- Traffic control
- Opening to traffic
- Daily working schedule

WITH THE RIGHT EQUIPMENT, RIGHT KNOW HOW, AND PROPER INSPECTION A SUCCESSFUL PROJECT IS POSSIBLE

Quarry Road, Victorville, CA

QUESTIONS?

Corey J. Zollinger, P.E.

CEMEX, Inc

Director – Paving Solutions

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713-722-6084

Central Freight Distribution Ctr. Austin, Texas - 1987

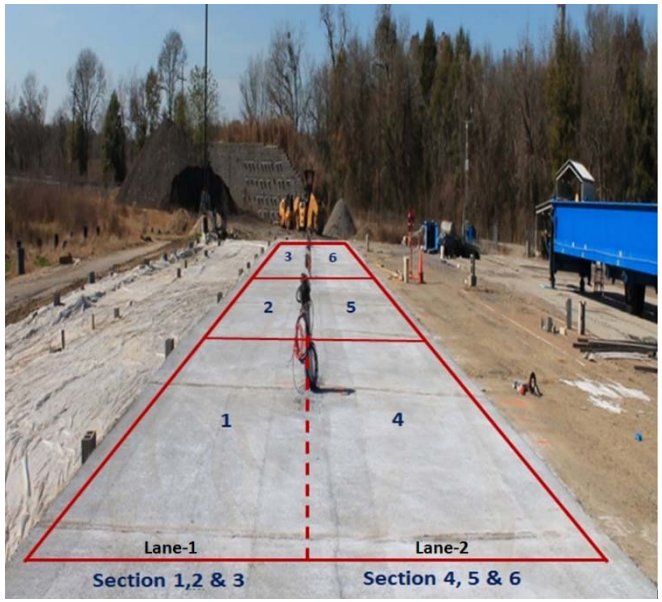
- Truck terminal
  - 7” & 8” pavements
  - 90,000 sy
  - RCC bid 25% less than asphalt
  - Peltz Companies
- Natural cracks
  - 23-50’ spacing
  - Routed/sealed @ 5 yr
- Continuous use, little maintenace @ 30 yrs:
  - Still performing – now used for post office and UPS
  - ~5,500 sy repairs performed in 2014 (10%)

Results from LTRC's Accelerated Loading Facility

Tyson D. Rupnow, Ph.D., P.E.
Zhong Wu, Ph.D., P.E.
Moinul Mahdi – Ph.D. student

Constructed RCC Test Sections

- Six full-scale RCC pavement test sections were constructed at Pavement Facility of Louisiana Transportation Research Center (LTRC)
  - Each section: 71.7-ft long and 13-ft wide



8 " RCC
12 "Cement Treated Base
Existing Subgrade

Section 1
(8+12RCC)

6 " RCC
12 "Cement Treated Base
Existing Subgrade

Section 2
(6+12RCC)

4"RCC
12 "Cement Treated Base
Existing Subgrade

Section 3
(4+12RCC)

8 " RCC
8.5" Soil Cement Base
10" Cement Treated Subgrade
Existing Subgrade

Section 4
(8+8.5RCC)

6 " RCC
8.5" Soil Cement Base
10" Cement Treated Subgrade
Existing Subgrade

Section 5
(6+8.5RCC)

4"RCC
8.5 "Soil Cement Base
10" Cement Treated Subgrade
Existing Subgrade

Section 6
(4+8.5RCC)

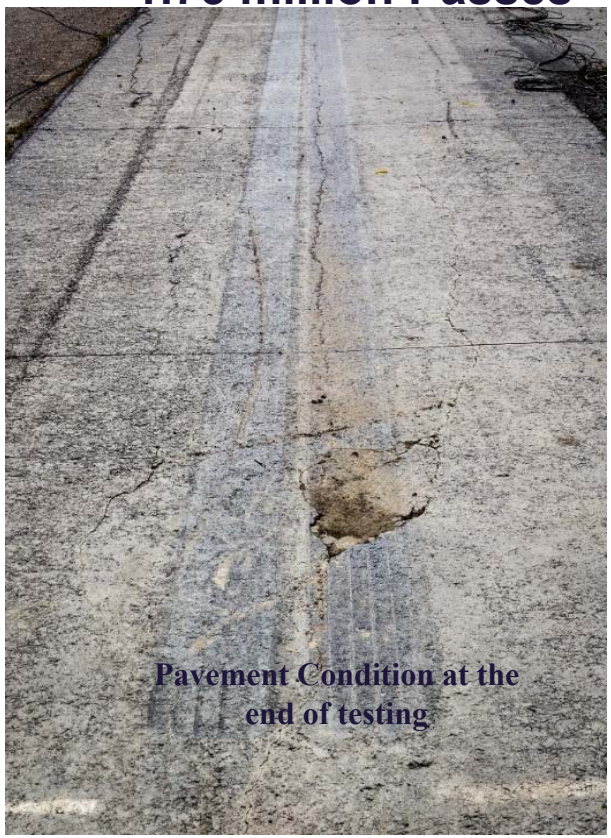
ATLaS30

Dual-tire load, 130psi
Load: up to 30 kips
Speed: 4~6 mph
Bi-directional loading
Effective length: 42-ft
About 10,000 passes/day

Distress Observed (6+8.5RCC) – Section 5

- **Visual Distresses**
  - Longitudinal cracks were observed along the wheel path and at the edge of the tire print
  - Pumping action was observed through cracks and joints
  - **87.4 million ESALs to failure**
  - ***1.9 million ESALs predicted***

1.75 million Passes

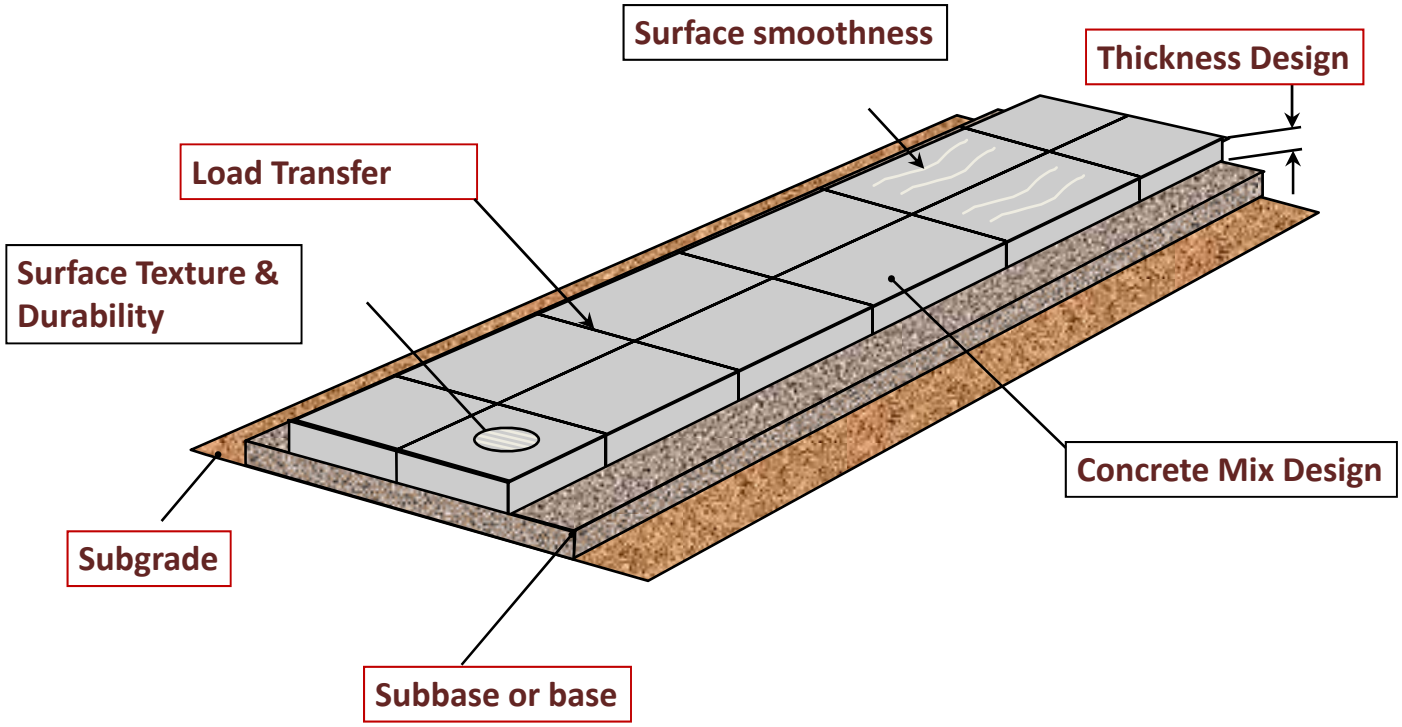


Pavement Condition at the end of testing

Conclusions

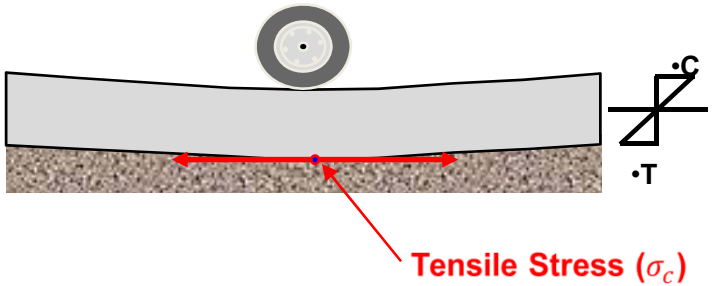
- The ATLaS30 loading results generally indicate that
  - a thin-RCC over soil cement pavement structure has a superior load carrying performance
  - Recommendation to select and build several field RCC test sections on those Louisiana highways where the pavements are often encountered by heavy truck loading
    - To validate the APT performance and provide further implementation guidelines
  - ***8-inch sections will not to fail!***

RCC DESIGN FEATURES



THICKNESS IS DETERMINED BY LIMITING THE FATIGUE STRESS THAT WILL DEVELOP IN THE CONCRETE

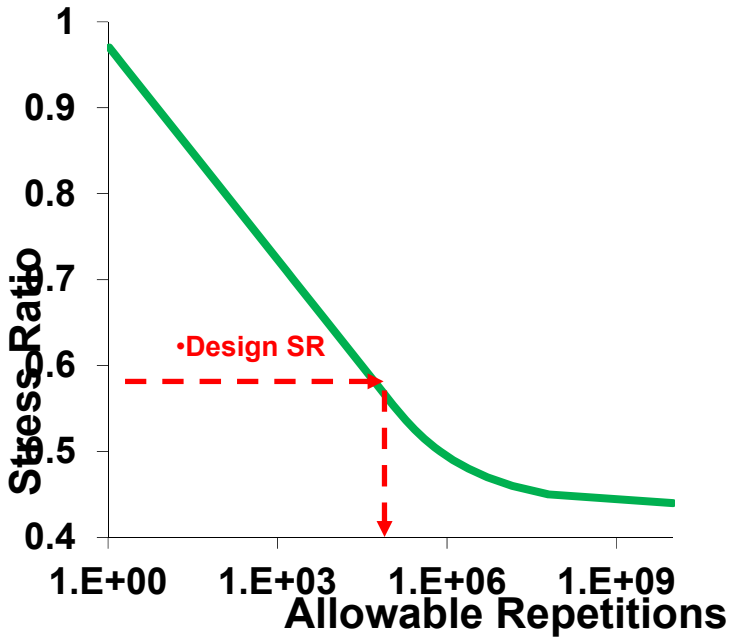
Bending a slab causes stresses in the bottom of the concrete



$$\text{Stress Ratio (SR)} = \frac{\sigma_c}{Mr}$$

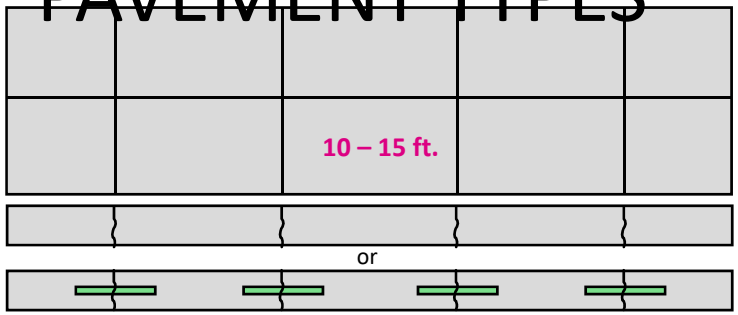
- Mr = 28-day Flexural strength (Modulus of Rupture)

•Flexural Strength Fatigue Curve



•Thickness is iterated until induced stress is low enough to carry the desired number of loads

THERE ARE THREE BASIC CONCRETE PAVEMENT TYPES

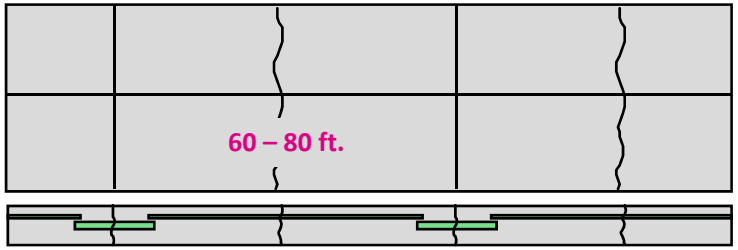


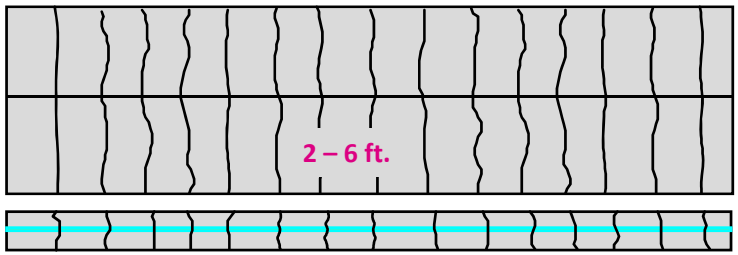
Jointed Plain Concrete Pavements (JPCP)
Jointed plain concrete pavements contain sawed joints so that the natural cracks occur at the joints and not elsewhere in the slab. The spacing between transverse joints is usually 10 to 15 ft. JPCP's typically have deformed steel tiebars at the longitudinal joints to hold the lanes together, but they do not contain other mesh reinforcement.

Depending on the slab thickness, JPCP's may contain smooth steel dowel bars at transverse joints to improve load transfer

Jointed Reinforced Concrete Pavements (JRCP)
JRCP's contain steel mesh reinforcement. With JRCP's, the joint spacing purposely increased and the reinforcing steel holds the mid-panel cracks that will develop together. The spacing between transverse joints is between 30 ft. and 100 ft.

The problem with JRCP's is that the steel ruptures, and the cracks start to open, move, and deteriorate. For this reason, **industry does not recommend building JRCP.**





Continuously Reinforced Concrete Pavements (CRCP)
CRCP's do not have transverse joints. Rather, they are designed with high amounts of steel reinforcement that hold the transverse cracks that do develop tightly together. The cracks usually develop at intervals of 3-5 ft.

Considered the premier concrete pavement

DO NOT SUPPORT JRCP

ACI 330R-08

- ACI 3.8.1 Distributed steel reinforcement

  "When the pavement is jointed to form short panel lengths that will minimize intermediate cracking, distributed steel reinforcement is not necessary.

  The practice of adding distributed steel to increase panel lengths has largely been discredited, and generally leads to excessive joint movements and interior panel cracks that deteriorate over time.

  Shorter un-reinforced panels are generally more economical and provide better performance."

Bureau of Public Roads

- *"In 1940, the U.S., Bureau of Public Roads [precursor to FHWA] conducted a series of tests to evaluate expansion joints, These tests found that expansion joints progressively close over the years causing greater openings at nearby contraction joints, This led to spalling, loss of aggregate interlock, and sealant failure, which in turn allowed water and incompressible into the joint causing pumping, faulting, and corner breaks. As a result, it was concluded that expansion joints should not be used in concrete pavements built with normal aggregates under normal temperatures with contraction joints spaced less than 60 ft (18 m)."*

American Concrete Pavement Association

***ACPA IS416P* states (see page 3):**
"… the sole purpose of the steel is to tightly hold together intermediate cracks that may be expected in longer panels. Distributed steel does not add to the load-carrying capacity of the pavement, nor compensate for poor subgrade conditions."

TxDOT

JRCP is not in line with TxDOT standards – The TxDOT *Pavement Design Guide* states :

"This [JRCP] rigid pavement design option is no longer endorsed by the department because of past difficulties in selecting effective rehabilitation strategies."

None of the recent pavement design procedures allow for JRCP (AASHTO, ACPA, or ACI)