Atkinson Blvd – Roseville, CA

THE SCIENCE / ART OF RCC MIX DESIGN AND QC

Corey J. Zollinger, P.E.

CEMEX

RCC Pavement Council

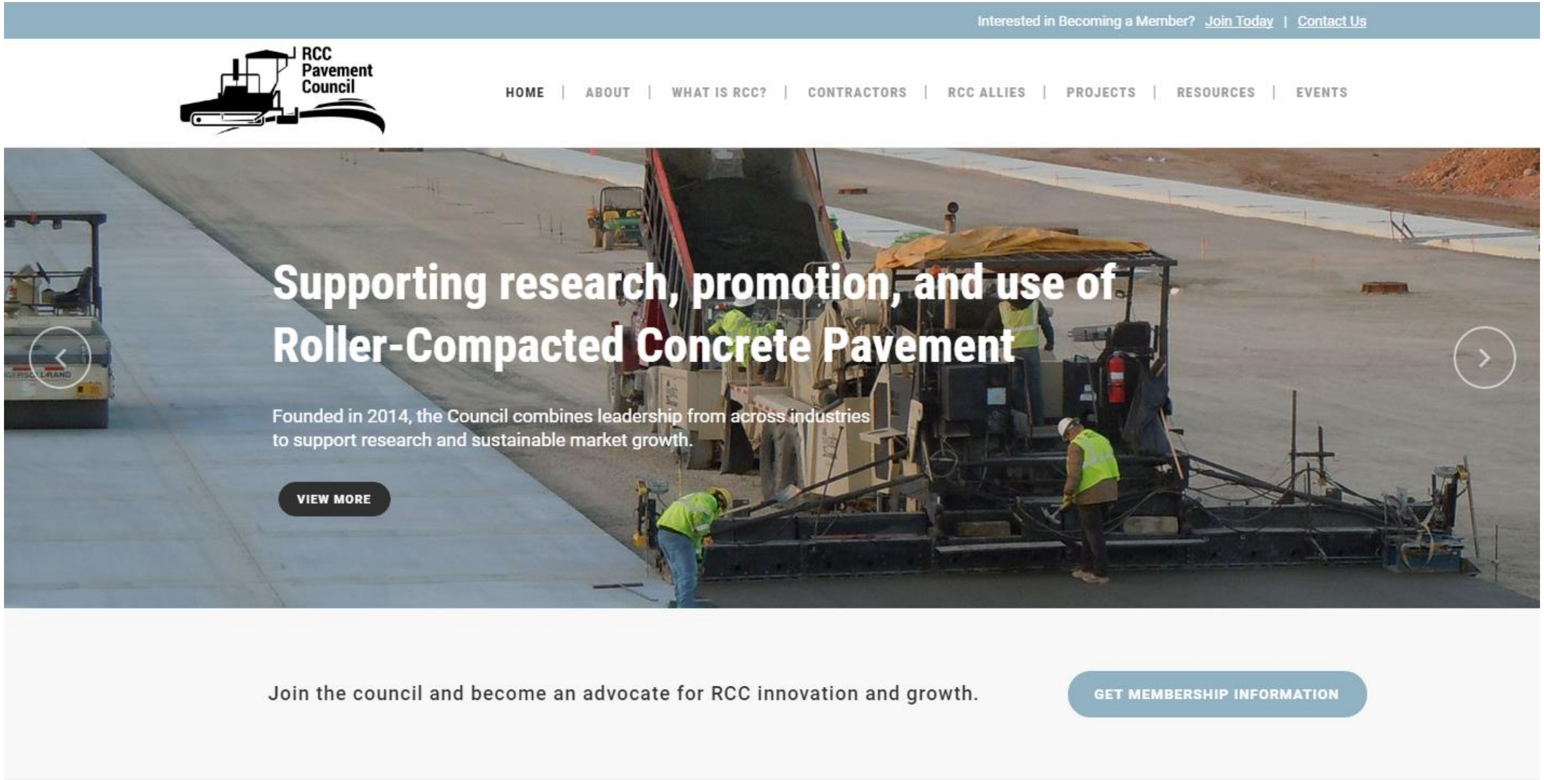
CCT CEMENT COUNCIL OF TEXAS


Hickory Street– Roseville, CA

KEY QUESTIONS TO BE ANSWERED TODAY

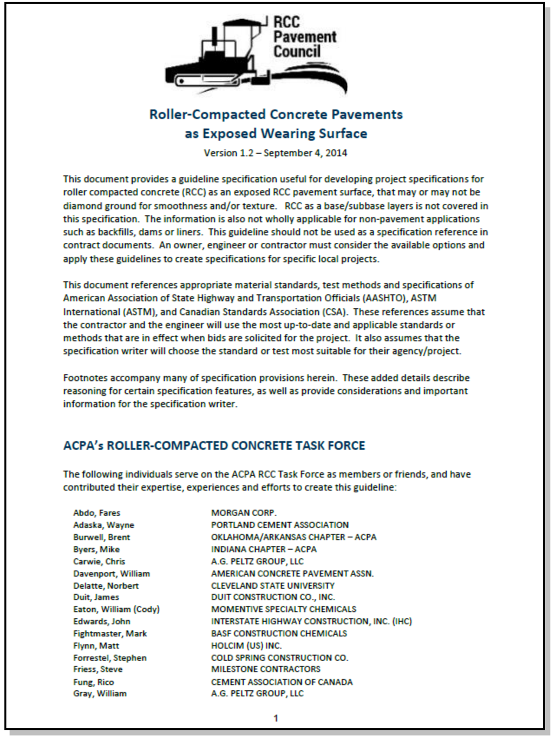
- What are the Keys to Aggregate & Sand Selection?
- How are Mix Volumetrics Determined?
- Understanding Mix Behavior
- What are the Key Steps to Mix Quality Control?

RCC PAVEMENT COUNCIL FOUNDED IN 2014, PROVIDES SUPPORT FOR RESEARCH AND PROMOTION



TECHNICAL RESOURCES HAVE BEEN DEVELOPED

Construction Specifications & Guide Books are available


RCC Pavement Council

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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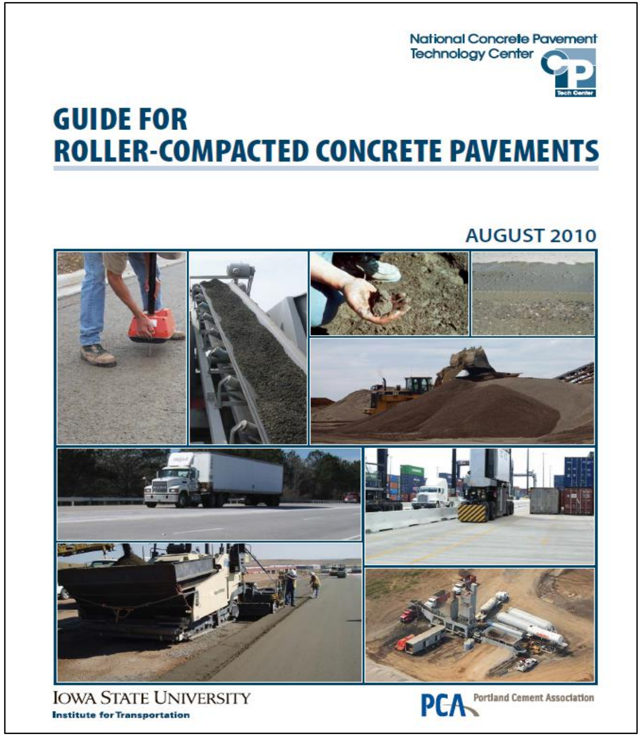
Guideline specification for Exposed Surface RCC pavements



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

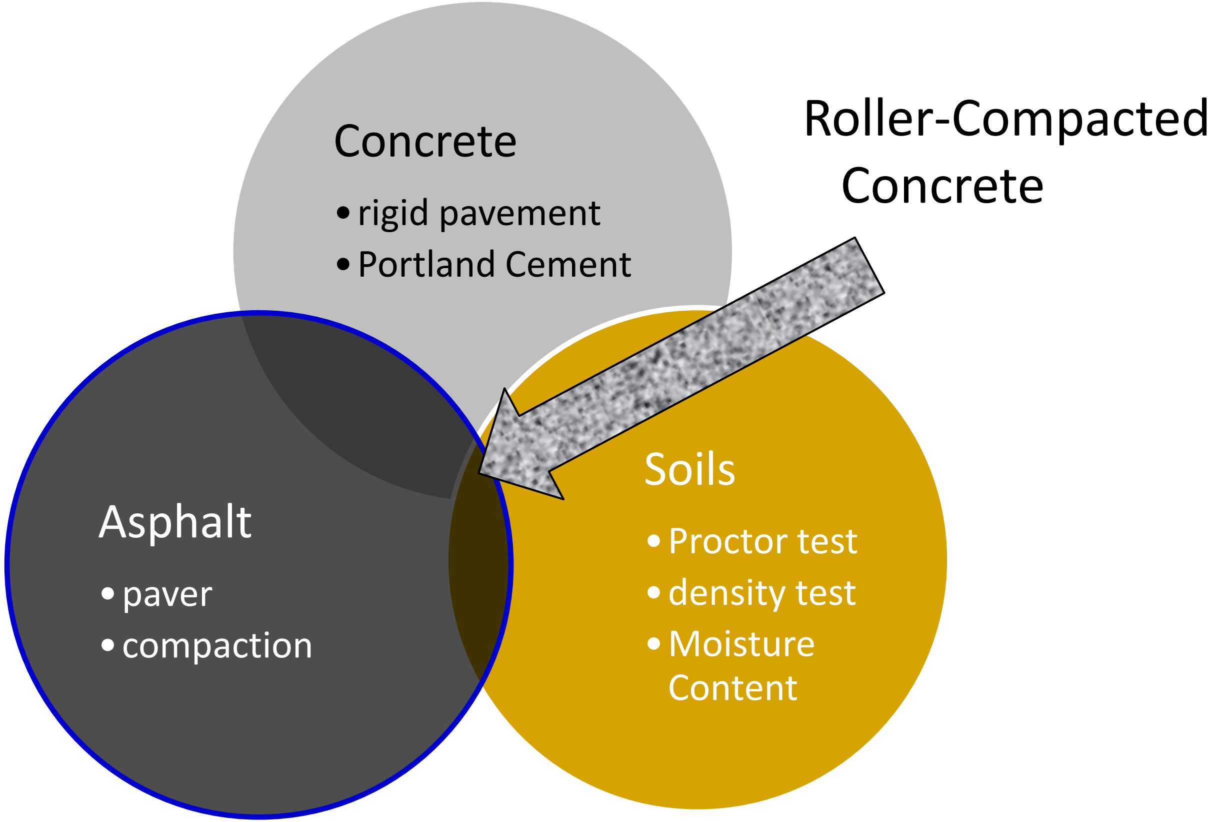
ROLLER COMPACTED CONCRETE IS A NEGATIVE SLUMP CONCRETE

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
- No internal vibration (consistency of damp gravel).

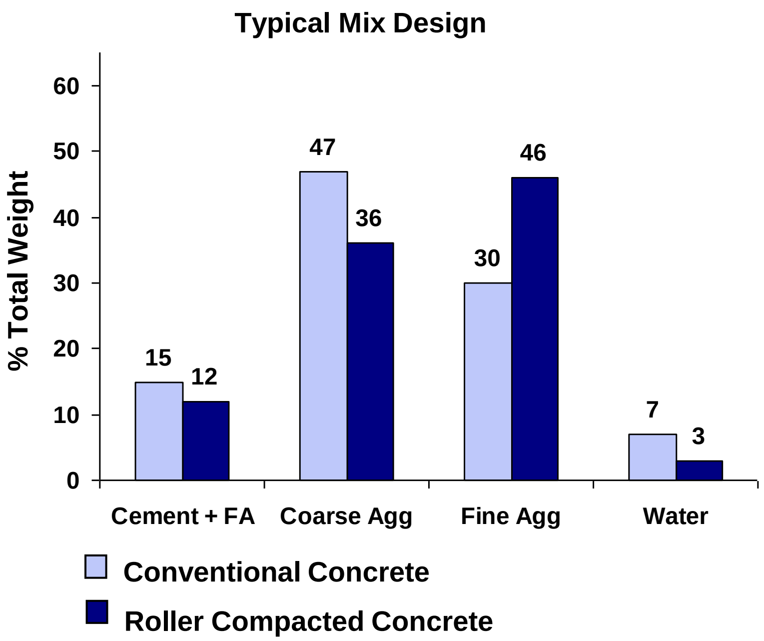
RCC is a concrete pavement that is placed in a different way!

MULTIPLE PERSONALITIES



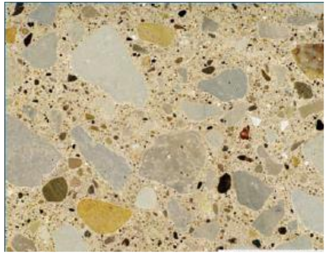
RCC MIX DESIGN USES SAME MATERIALS AS CONVENTIONAL CONCRETE, HOWEVER IN DIFFERENT COMBINATIONS

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

MIXTURE DESIGN PROCEDURE

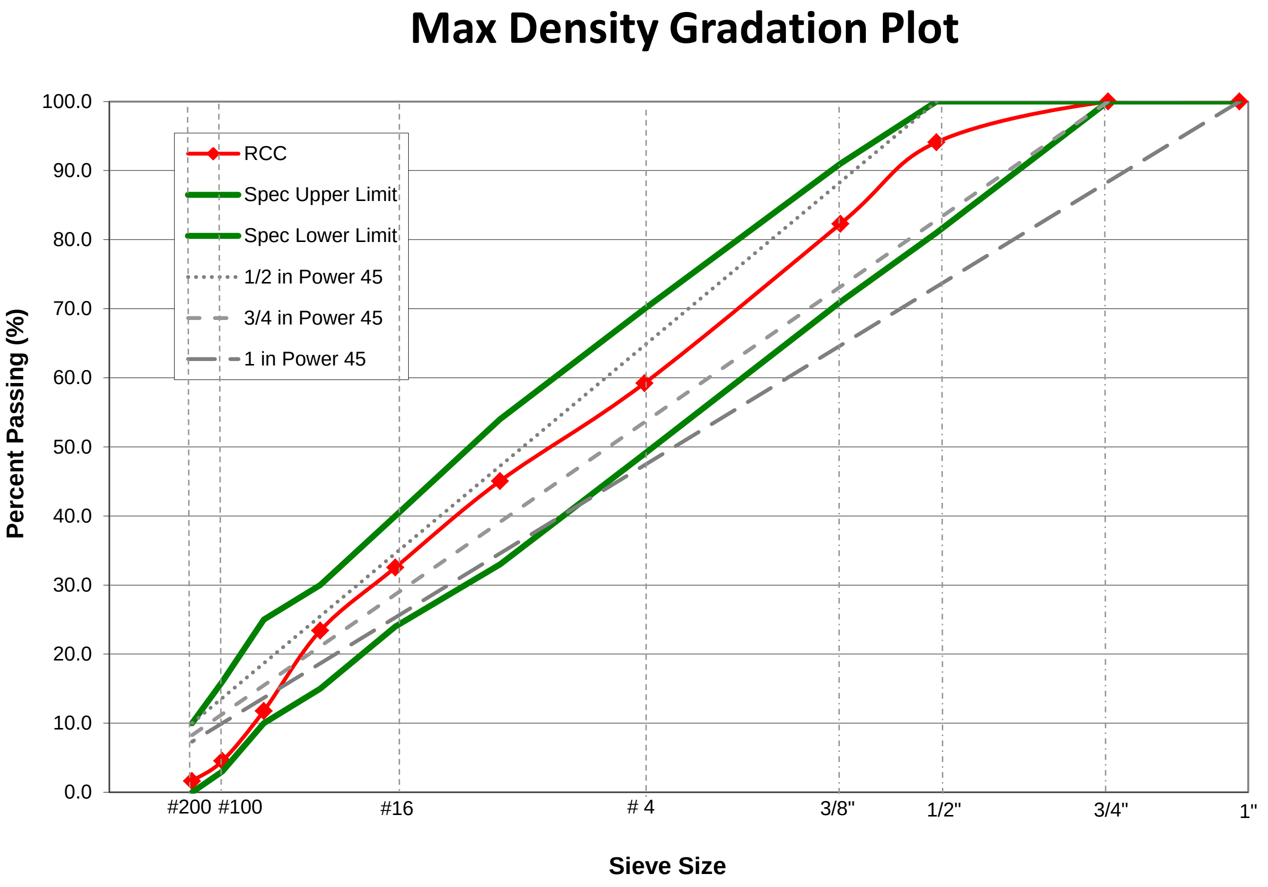
Step 1: Select Coarse Aggregate, Intermediate Aggregate, & Sand

- **Most important aspect of mix design (85% of mixture)**
- **Selection based on gradation test results of available aggregates**
- **Quantity of aggregate sources depends on # of aggregate bins at production plant**
- **Need to achieve a balance of angularity and surface appearance**

Basic Criteria

- **ASTM C33**
- **2 or more stockpiles**
- **From qualified sources from State DOT qualified products listings**
- **Plasticity Index less than 5**

MOST COMMON AGGREGATE SELECTION PROCEDURE



MOST COMMON AGGREGATE SELECTION PROCEDURE

Sieve Size	Lower & Upper Specification Limits 1/2 in (12.5 mm)		Lower & Upper Specification Limits 3/4 in (19.0 mm)	
1.5 in. (37.5 mm)				
1 in. (25 mm)			100.0	100.0
3/4 in. (19 mm)	100.0	100.0	95.0	100.0
1/2 in. (12.5 mm)	81.0	100.0	70.0	95.0
3/8 in. (9.5 mm)	71.0	91.0	60.0	85.0
No. 4 (4.75 mm)	49.0	70.0	40.0	60.0
No. 8 (2.36 mm)	33.0	54.0	30.0	50.0
No. 16 (1.18 mm)	24.0	40.0	20.0	40.0
No 30 (600 ųm)	15.0	30.0	15.0	30.0
No 50 (300 ųm)	10.0	25.0	10.0	25.0
No. 100 (150 ųm)	2.0	16.0	2.0	16.0
No 200 (75 ųm)	0.0	8.0	0.0	8.0

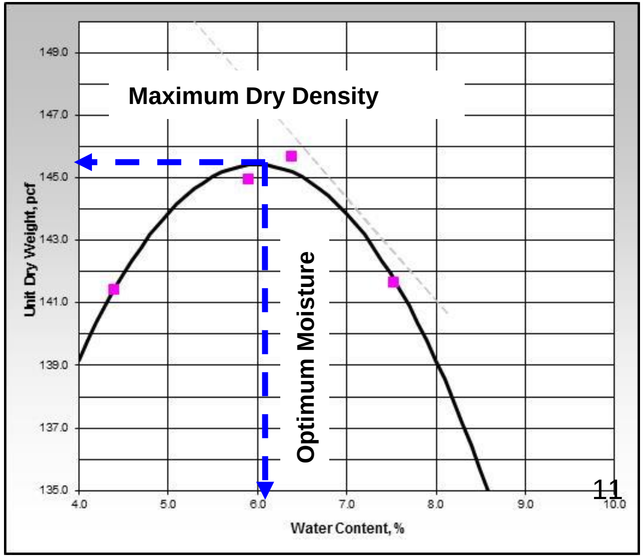
MIXTURE DESIGN PROCEDURE

Step 2: Select a mid – range cementitious content

- **Minimum 450 lbs cement / CY**
- **12-14% 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**

- ***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)**

(ASTM D1557)



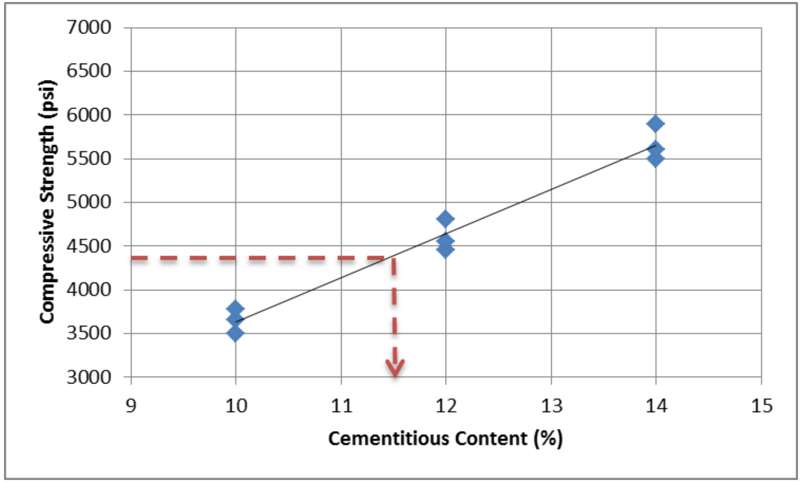
MIXTURE DESIGN EXAMPLE

Mix Quantities			
Max Dry Density (lbs/CF)		145.0	Proctor Test
Max Wet Density (lbs/CF)		152.8	
Optimum % Moisture		5.4%	
Coarse Aggregate #1 absorption %		1.1%	Aggregate Properties
Fine Aggregate #1 absorption %		1.7%	
Coarse Aggregate #2 absorption %		1.1%	
Fine Aggregate #2 absorption %		0.0%	
Target CA #1 %	1/2" x #8	20	Combined Gradation
Target FA #1 %	Concrete Sand	55	
Target CA #2 %	3/8" x 1/4" Crushed	25	
Target FA #2 %	0	0	

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



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MIXTURE DESIGN VOLUMETRICS

Mix Quantities		
Max Dry Density (lbs/CF)		145.0
Max Wet Density (lbs/CF)		152.8
Optimum % Moisture		5.4%
Coarse Aggregate #1 absorption %		1.1%
Fine Aggregate #1 absorption %		1.7%
Coarse Aggregate #2 absorption %		1.1%
Fine Aggregate #2 absorption %		0.0%
% Cementitious		11.5%
% Cement		11.5%
% Fly Ash (of cement replace)		0.0%
Target CA #1 %	1/2" x #8	20
Target FA #1 %	Concrete Sand	55
Target CA #2 %	3/8" x 1/4" Crushed	25
Target FA #2 %	0	0

Mix Weight (lbs) Per CY

Water Weight = (152.8-145.0) x 27 = 211

Total Dry Materials = 145.0 x 27 = 3915

1. Select Cement content
2. CA = (Total Dry-cement) x % Target

   CA = (3915-450) X .2 = 693

SSD Weight

1. CA = Dry weight x (1 +%SSD)

Ingredient		Batch Weight (Dry) (lbs/CY)	Batch Weight (SSD) (lbs/CY)	Specific Gravity (SSD)	Absolute Volume (CF)
Cement		450	450	3.150	2.289
Fly Ash		0	0	2.350	0.000
CA #1	1/2" x #8	693	701	2.680	4.190
FA #1	Concrete Sand	1906	1938	2.630	11.810
CA #2	3/8" x 1/4" Crushed	866	876	2.680	5.237
FA#2	0	0	0	2.570	0.000
Total Water content (lbs)		211	211		
Water in Aggregates (lbs)		0.0	49.5		
Water added by Plant (Free Water) (lbs)		211.4	161.9	1.000	2.594

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The "Typical" Mix Design parameters can then be calculated

Total Final Volume (CF)			26.120
Calculated Air Volume (CF)			0.880
Calculated % Air Volume			3.26%
Water absorbed in Aggregates	49.55		
Free Water	162		
W/CM Ratio	0.36		
Aggregate / Cement Ratio	7.70		

IMPROVED UNDERSTANDING OF “AGGREGATE PROPERTIES” IMPACT ON “COMPACTED BEHAVIOR”

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

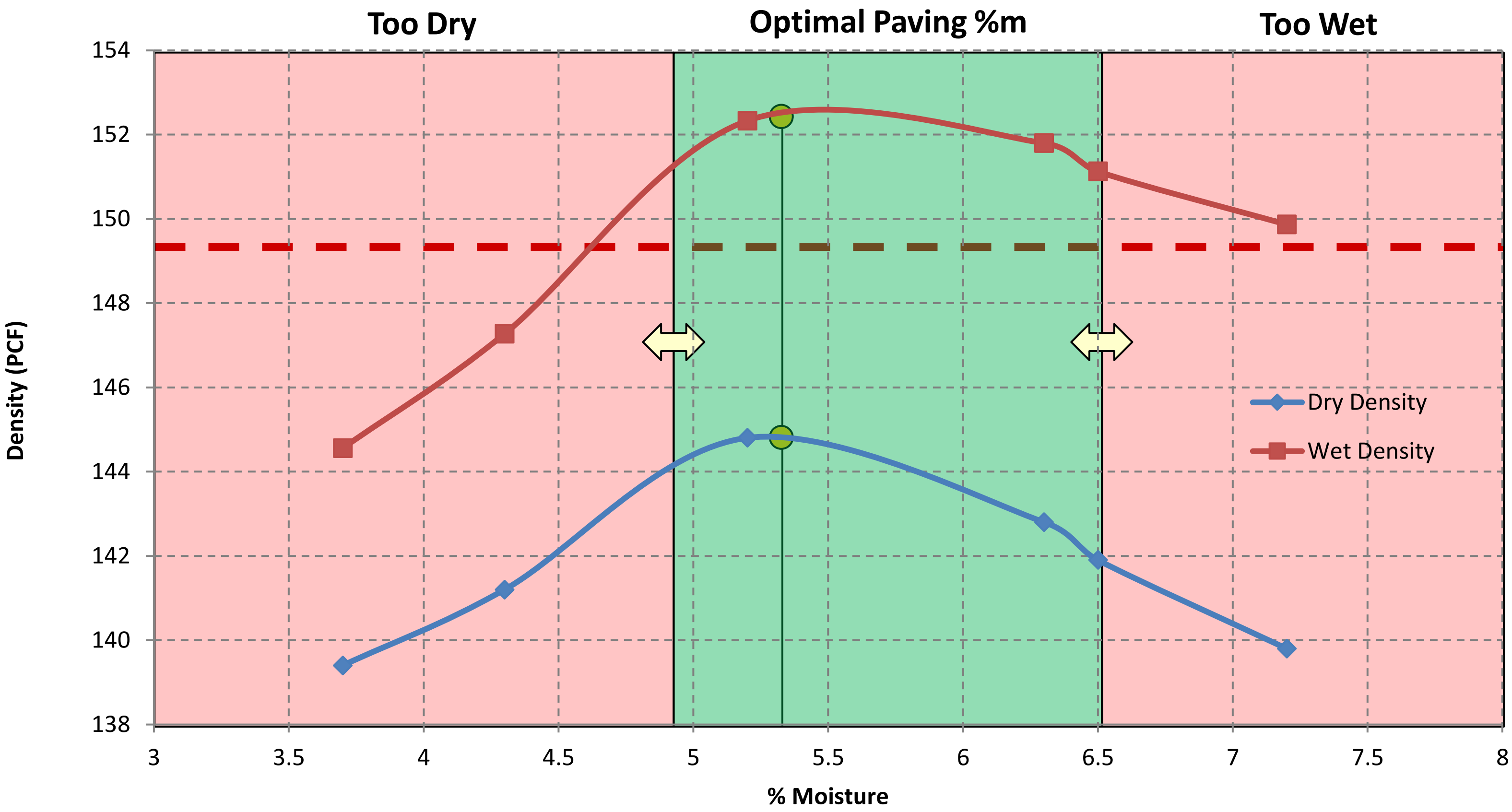
RCC Aggregate 45 Power Gradation
Manufactured Sand Vs Natural Sand

Mix Design	Mix #1 (Man Sand)	Mix #2 (Conc Sand)

KEY QUESTIONS TO BE ANSWERED TODAY

- **What are the Keys to Aggregate & Sand Selection?**
- **How are Mix Volumetrics Determined?**
- **Understanding Mix Behavior**
- **What are the Key Steps to Mix Quality Control?**

MIXTURE DESIGN
What Is The Optimal Paving Moisture Content?



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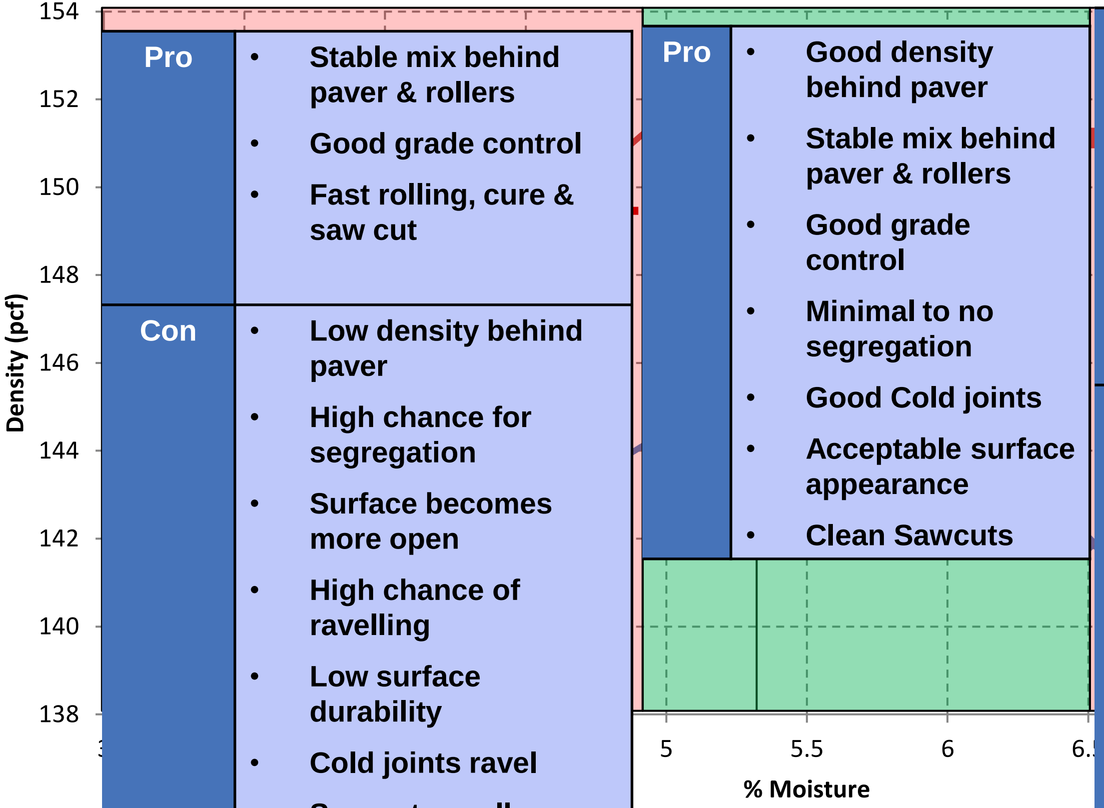


Too Dry

Pro
- Stable mix behind paver & rollers
- Good grade control
- Fast rolling, cure & saw cut

Con
- Low density behind paver
- High chance for segregation
- Surface becomes more open
- High chance of ravelling
- Low surface durability
- Cold joints ravel
- Saw cuts spall

Optimal Paving %m

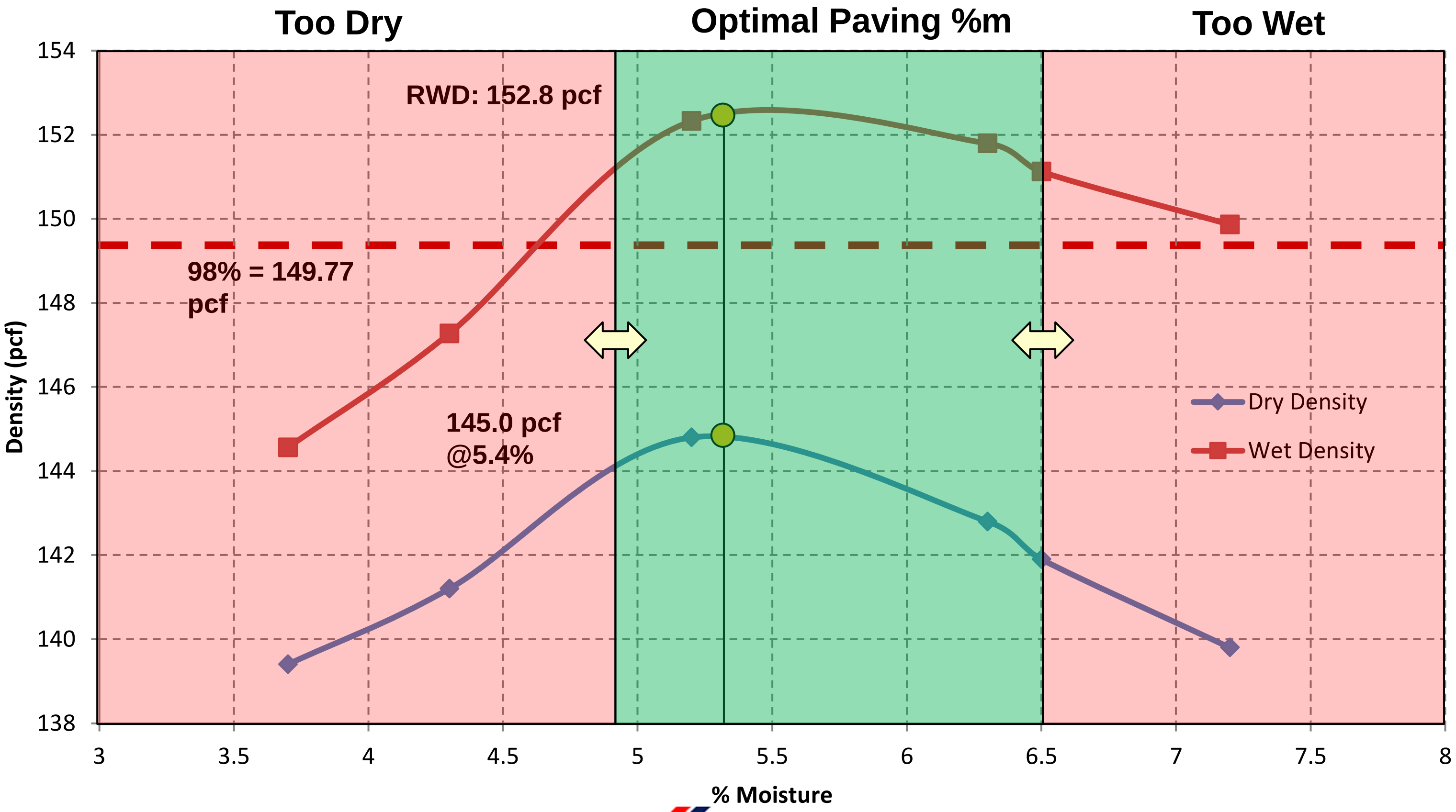
Pro
- Good density behind paver
- Stable mix behind paver & rollers
- Good grade control
- Minimal to no segregation
- Good Cold joints
- Acceptable surface appearance
- Clean Sawcuts

Too Wet

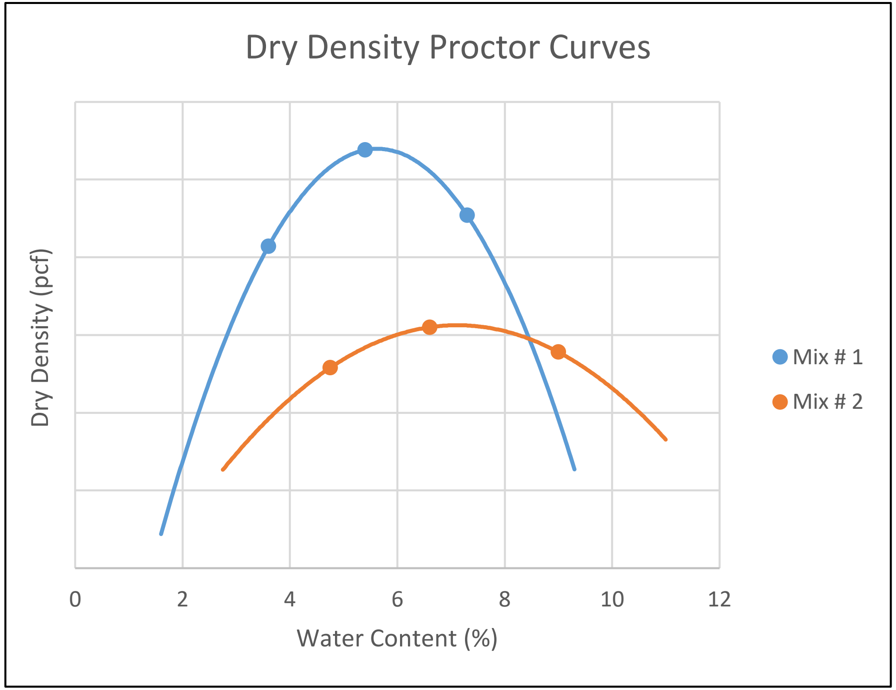
Pro
- High Density behind paver
- Low mix segregation
- Good cold joints
- Tight Surface appearance
- Clean sawcuts

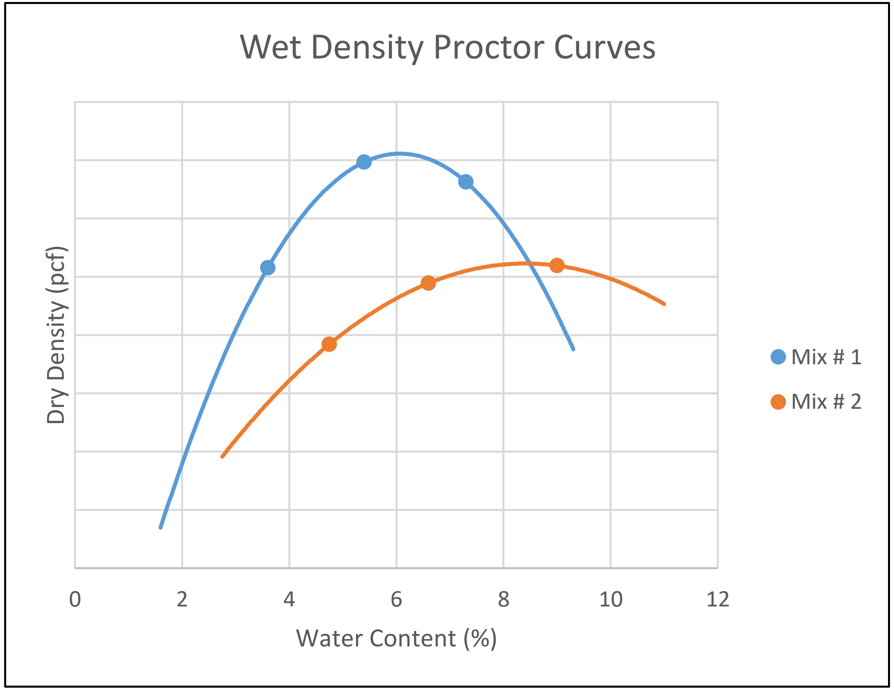
Con
- Instable mix behind paver
- Poor grade control
- Delay roller compaction time
- Delay curing time
- Delay sawcutting time

MIXTURE DESIGN
What Aggregate Properties Change the Optimal Paving Moisture Content Window??



DOES THE SHAPE OF THE PROCTOR CURVE MATTER?
What Aggregate Properties Affect the Shape of the Curve?



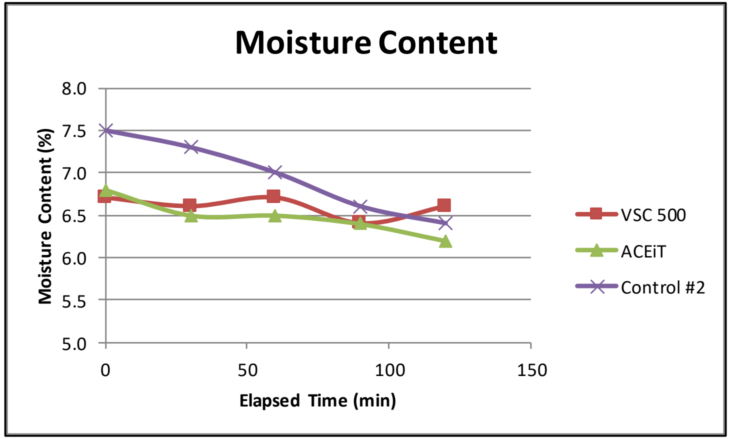


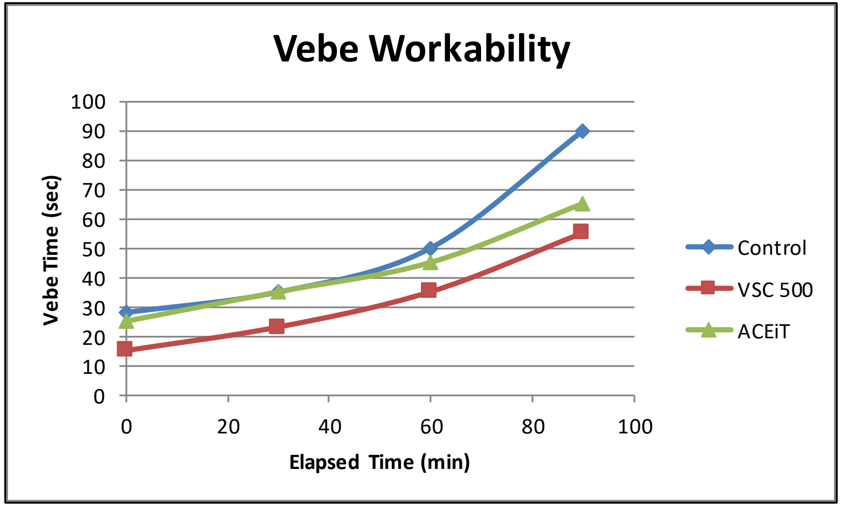
Mix #2 will have a lower sensitivity to moisture fluctuations and be "easier" to pave

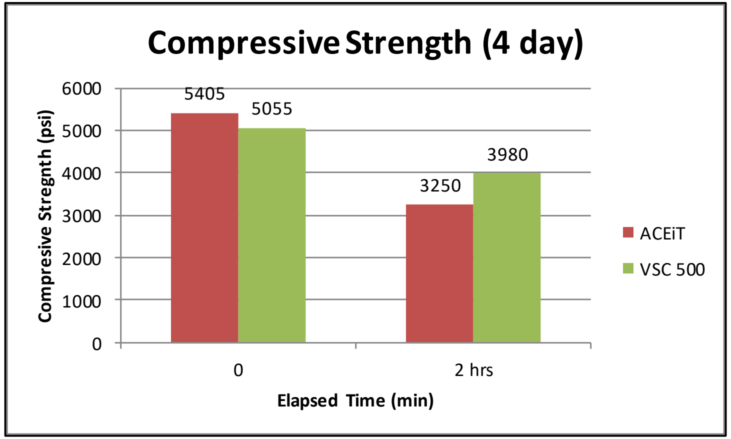
ADMIXTURES CAN HELP MITIGATE HOT / DRY WEATHER

Intended Goals of the Research

- **Compare workability and moisture retention of mixes with various admixtures**

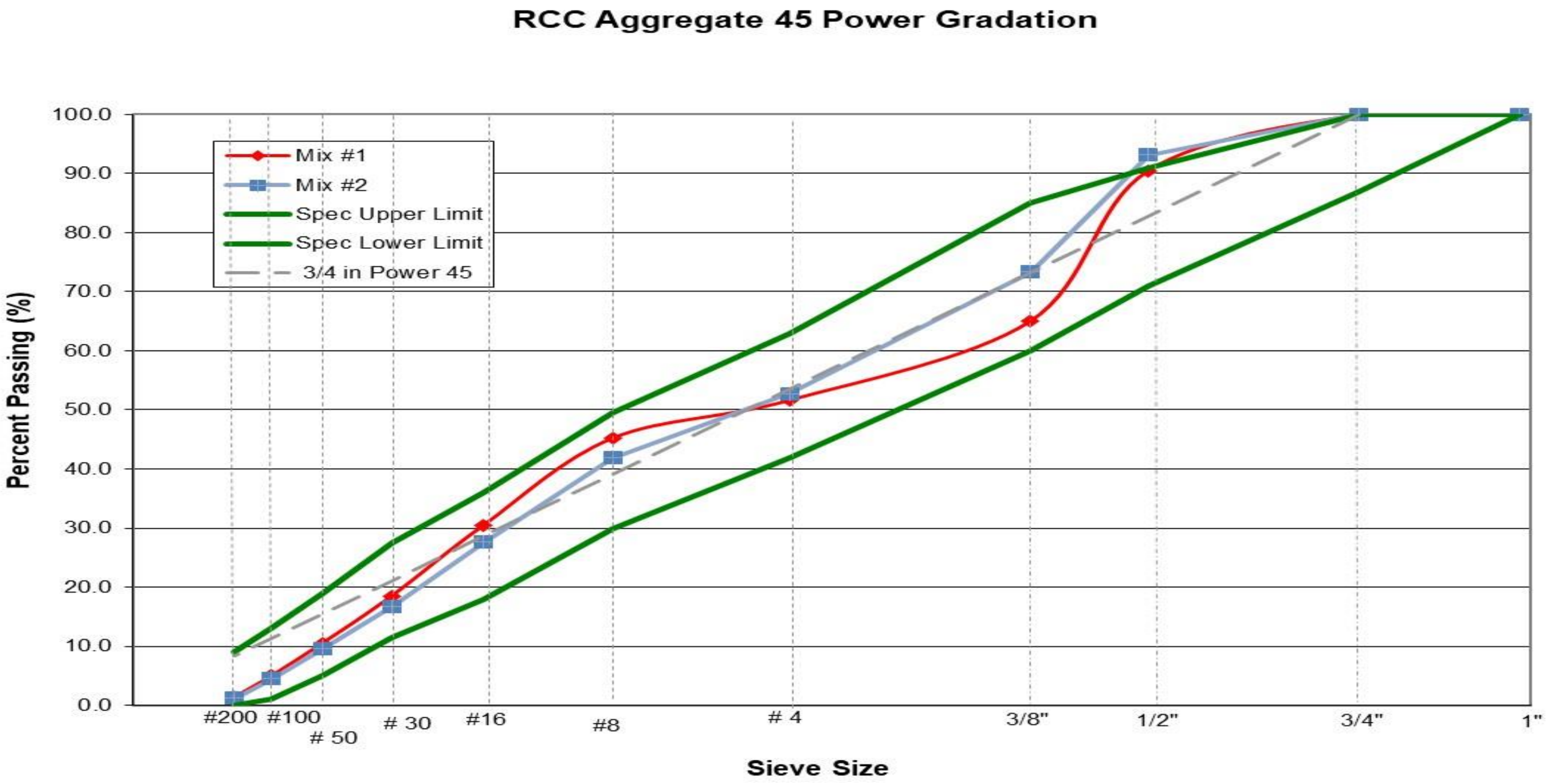






THE SURFACE APPEARANCE AND TEXTURE OF RCC IS DEPENDANT ON PAVER TYPE AND AGGREGATE SELECTION

CASE STUDY: Santa Rosa, CA Fulton Road Mix Design



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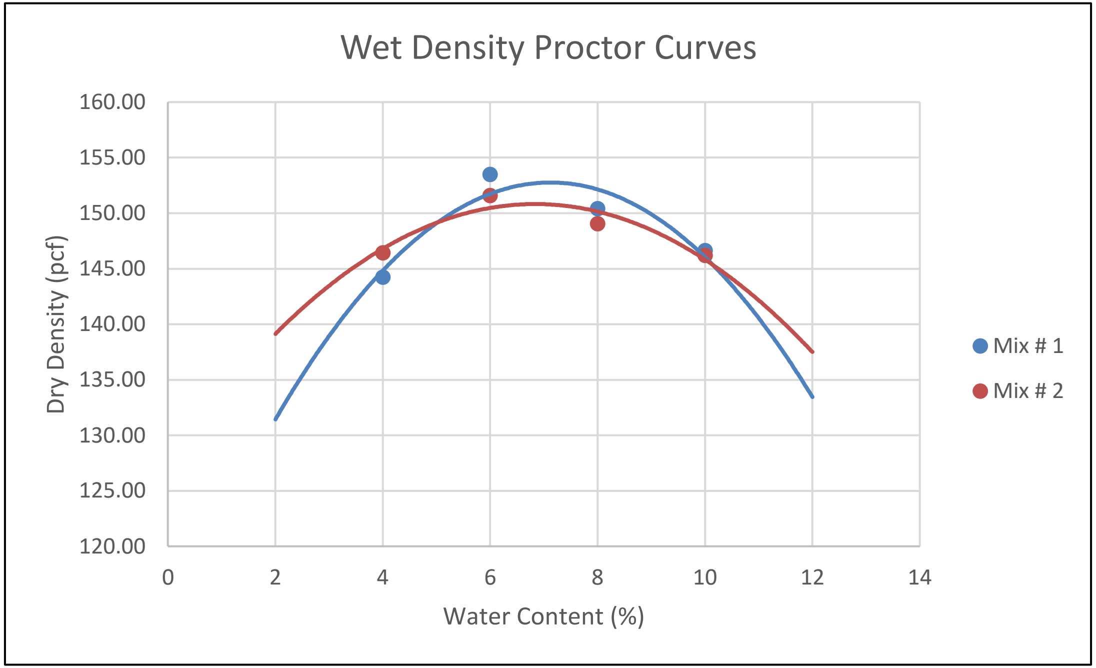

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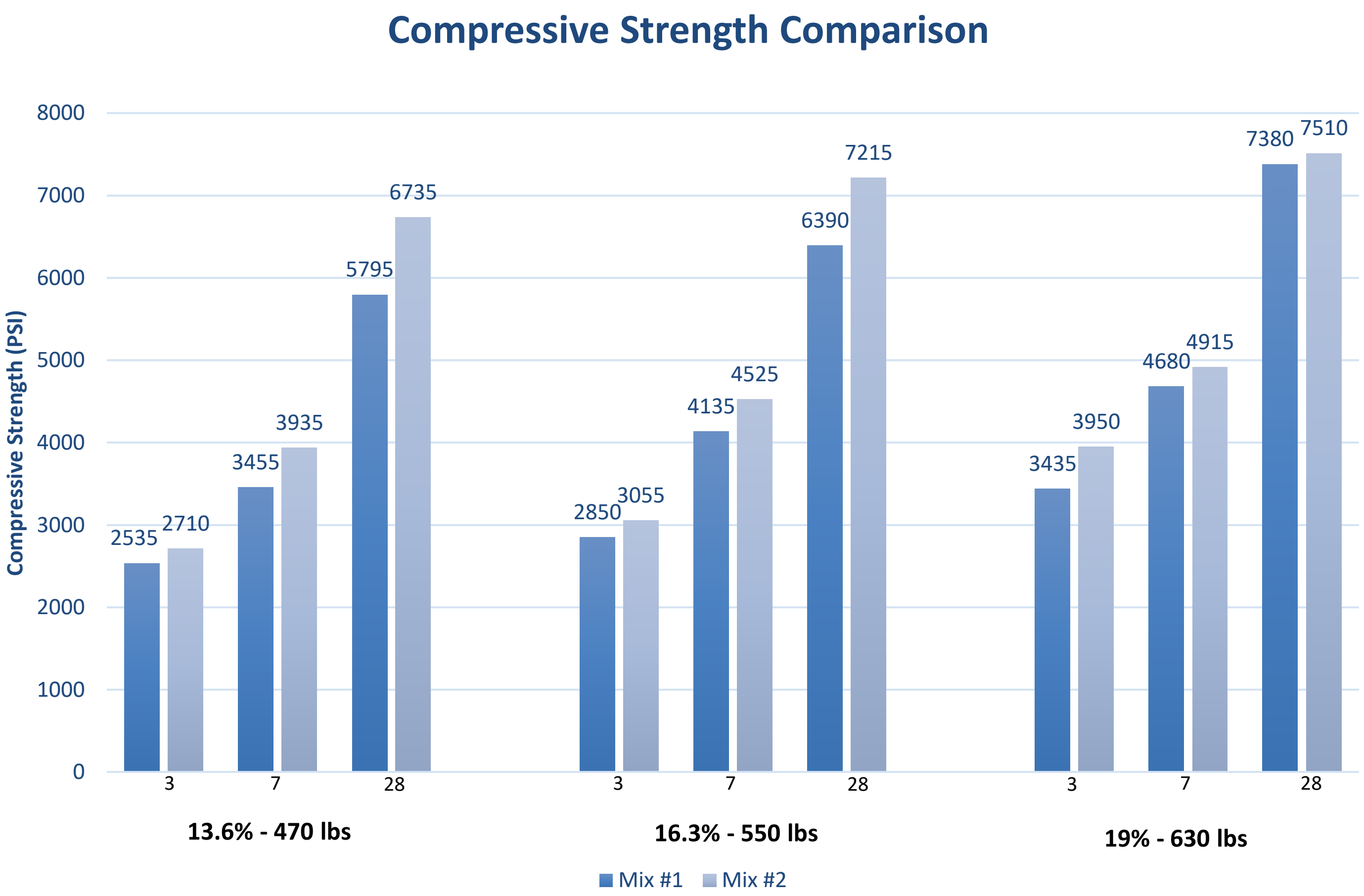


* All Mixes are 50% cement / 50% Slag

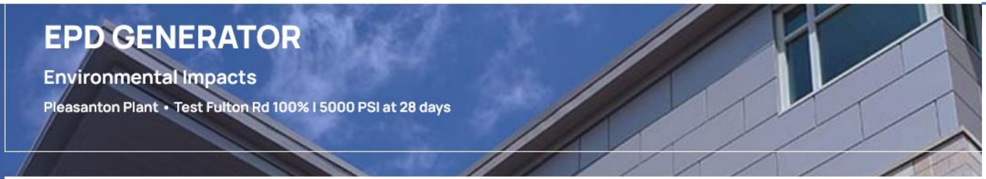

YK5K34
HD+110i
ISUZU
GREENVALLEY

CASE STUDY: Santa Rosa, CA Fulton Road Mix Design

climate earth | CEMEX

Conventional Concrete Mix

Why Climate Earth? EPD 101 Solut



Declared Unit:

1 m3 of concrete

Global Warming Potential (kg CO_2-eq)	399
Ozone Depletion Potential (kg CFC-11-eq)	6.93E-6
Acidification Potential (kg SO_2-eq)	1.03
Eutrophication Potential (kg N-eq)	0.24
Photochemical Ozone Creation Potential (kg O_3-eq)	21.4
Abiotic Depletion, non-fossil (kg Sb-eq)	5.53E-6
Abiotic Depletion, fossil (MJ)	2,595
Total Waste Disposed (kg)	0.92
Consumption of Freshwater (m^3)	3.98

Product Components:
natural aggregate (ASTM C33), Portland cement (ASTM C150), batch water (ASTM C1602), admixture (ASTM C494), slag cement (ASTM C989)

Disapprove & Re-Work | Submit Mix & Publish EPD | Save Mix as Draft

45% Carbon Reduction from Conventional Concrete project 1 mile away

RCC Mix

CEMEX

Why Climate Earth? EPD 101 Solutions

Declared Unit:

1 m3 of concrete

Global Warming Potential (kg CO_2-eq)	218
Ozone Depletion Potential (kg CFC-11-eq)	6.21E-6
Acidification Potential (kg SO_2-eq)	1.47
Eutrophication Potential (kg N-eq)	0.22
Photochemical Ozone Creation Potential (kg O_3-eq)	35.5
Abiotic Depletion, non-fossil (kg Sb-eq)	1.43E-5
Abiotic Depletion, fossil (MJ)	1,687
Total Waste Disposed (kg)	0.83
Consumption of Freshwater (m^3)	3.54

Product Components:
natural aggregate (ASTM C33), Portland cement (ASTM C150), slag cement (ASTM C989), batch water (ASTM C1602), admixture (ASTM C494)

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KEY QUESTIONS TO BE ANSWERED TODAY

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RCC MIXTURE MOISTURE CONTENT TESTING

TEST STANDARD	**ASTM C566**
PRECISION	**0.79% (d2s for aggregate)**
MIN. FREQUENCY	**Often / As needed**
ACCEPTANCE	**± 1-2% of Optimum**

IN-PLACE WET MAT & JOINT DENSITY TESTING

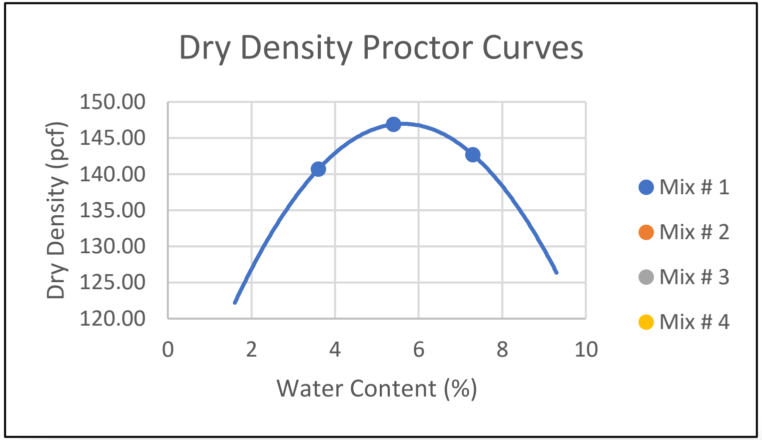
TEST STANDARD	ASTM C1040
PRECISION	1.4 pcf (d2s)
MIN. FREQUENCY	300 – 750 CY
ACCEPTANCE	Ave. of 4 ≥ 98% RC 0 < 96% RC

FABRICATING COMPRESSION TEST CYLINDERS

EQUIPMENT

Best Practice Recommendations

1. Proctor Curve – Mix Specific
2. Build and Eat Stockpiles Consistently
3. Moisture Content (Dry Back) - Aggregate / Sand Stockpiles
4. Produce Mix
5. Moisture Content (Dry Back) – Mix @ Plant
6. Moisture Content (Dry Back) – Mix @ Paver
7. Nuclear Density – Behind Paver
   Calibrate Nuclear Gauge Moisture to Dry Back
8. Nuclear Density – Behind Rollers
9. 1 Point Proctor – Check Curve



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.

RCC Pavement Council: Chairman

CEMEX: Director – Sustainable Infrastructure Solutions

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