Design and Construction of Sustainable Concrete Pavements in Desert Environments

Our workshop objectives

1. Share knowledge about recent research and best practices for concrete pavements.
2. Provide guidance for improving the outcomes of concrete pavement projects in desert climates.
3. Provide a forum for sharing pavement project successes and challenges.
## Design and Construction of Sustainable Concrete Pavements in Desert Environments

1. **Concrete Mixtures for Pavement** — This session will present the “How’s & Why’s” of specifying and proportioning cements, SCMs, admixtures, and aggregates for desert pavements.  
   Peter Taylor, CP Tech Center  
   **Tuesday, April 19th**  
   **9:00 to 10:15 am**

2. **Pavement Design and Critical Properties** — Designing and specifying pavements for desert environments requires a solid understanding of how design relates to placement and performance.  
   Tom Van Dam, NCE  
   **Tuesday, April 26th**  
   **9:00 to 10:15 am**

3. **Concrete Pavement Inspection and Testing** — Pavement quality is controlled through comprehensive inspection and testing requirements. Desert environments present added paving risks that should be accounted for.  
   Mike Praul, FHWA  
   **Tuesday, May 10th**  
   **9:00 to 10:15 am**

   Angel Mateos, UCPRC; Dave Rath, Southwest Concrete Paving Company; and Matt Fonte, Fonte & Company  
   **Tuesday, May 24th**  
   **9:00 to 10:15 am**
Thank You to our Workshop Supporters
Dr. Taylor leads internationally recognized research at the National Concrete Pavement Technology Center. His high-impact work has resulted in the development of specifications such as the AASHTO PP 84: “Developing Performance Engineered Concrete Pavement Mixtures.”

Additionally, his research has helped transportation agencies save millions of dollars by preventing premature joint failures, and improving the performance of concrete mixtures.
Design and Construction of Sustainable Concrete Pavements in Desert Environments

Session 1: Concrete Mixtures for Pavements

Dr Peter Taylor
Mixtures for Desert Environments

• What’s special about the desert
• Materials
• Mixture
What’s special about the desert?

• Its dry
• Temperatures swing
Concrete and Water

- At mixing – less water is better
- After setting – more water is better
- Later on – less water is better
Concrete Materials

What controls performance?

- 9–15% Cement
- 15–16% Water
- 25–35% Fine aggregate
- 30–45% Coarse aggregate

Paste (cement + water)

Mortar (paste + fine aggregate)

Concrete (mortar + coarse aggregate)
Aggregates

- Aggregates comprise ~70% of the volume of a concrete mix.
- Aggregate properties influence:
  - Water demand
  - Durability
  - Workability
  - Dimensional changes
Aggregates in Concrete

- Physical properties to consider:
  - Contamination
  - Gradation
  - Absorption
  - Surface texture
  - Particle shape
Aggregate Gradation

- Combined gradation controls
  - Workability
  - Volume of paste needed
Moisture State

- Uniformity

<table>
<thead>
<tr>
<th>State</th>
<th>Oven dry</th>
<th>Air dry</th>
<th>Saturated, surface dry</th>
<th>Damp or wet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total moisture</td>
<td>None</td>
<td>Less than potential absorption</td>
<td>Equal to potential absorption</td>
<td>Greater than absorption</td>
</tr>
</tbody>
</table>

Grove
 Aggregate Durability

Aggregate-related distresses include the following:

- Alkali-aggregate reactivity (ASR / ACR)
- D-cracking
- Surface popouts
- Polishing
Cementitious Materials

**Hydraulic cement** – reacts under water, creates CH

- Portland Cement
- Slag Cement
- Class C Fly Ash
- Class F Fly Ash
- Silica Fume

**Pozzolan** – reacts with cement and water, consumes CH

Not to scale
Portland Cements

- Type I – general use (ASTM C 150)
- Type IL – general use (ASTM C 595)
Cement is Changing

Chemical Composition

Fineness

Percent

Year

0 10 20 30 40 50 60 70

C3S
C2S
C3A

Blaine m²/kg

Year

0 100 200 300 400 500

1900 1920 1940 1960 1980 2000 2020
Supplementary Cementitious Materials

- Fly ash
- Slag
- Natural pozzolan
- Silica fume
Sources

- Fly ash – coal fired utilities
- Slag – iron making
- Silica fume – ferro silicon
- Metakaolin – partially calcined clay
Supplementary Cementitious Materials
So What Do They Do?

- SCM’s change properties
- Means we have to allow for them
- Cracking risk changes
- Finishing and curing needs change
- Strength rate slows
- Permeability decreases (good)
Water

• Potable or
• Free of organics & contaminants
Water Reducers

Water

Cement

Freed Water

Cement

WR
Retarders

• Slow hydration
  ▪ Slows need for sawing in hot weather
  ▪ Reduces heat of hydration peak
  ▪ May reduce slump loss
  ▪ May improve long-term strength
  ▪ May increase risk of plastic cracking

• Often based on sugars
**Accelerators**

- Increase rate of hydration
  - Setting time decreased in cold weather
  - Increased early strength
  - May increase risk of shrinkage cracking
- Avoid chloride based products if steel is in the concrete
Fibers - Critical Properties

- Stiffness
- Bond
- Strength
- Size
- Durability
“Micro” vs. “Macro” Fibers

- **Micro (Low Volume Addition) Fibers**
  - Diameters < 0.004”
  - Polypropylene, Nylon, Carbon, Cellulose
  - 0.03 – 0.1% volume (0.5-1.5#/cy)

- **Macro (High Volume Addition) Fibers**
  - Diameters: 0.008 – 0.03”
  - Synthetic, Steel 0.2 – 1.0% volume [3 - 15#/cy (Synthetic) or 20-100#/cy (Steel)]
Effects of Fibers

- Do not affect strength
- Do increase toughness / strain capacity
Curing

- Keep the water in...
- Curing compound should be applied as soon as practical after finishing
- Should be white
- Poly-alpha-methylstyrene is effective
- Alternatives are water fogging, plastic sheeting, ponding

- How do we know it is good?
Internal Curing

- Provide curing water uniformly through the section
- Material should
  - Hold sufficient water
  - Hold the water until needed and not effect w/c
  - Give up water at high RH (desorption)
  - Not adversely effect the concrete quality
Proportioning
Proportioning Approaches Past

- Structural concrete 1:2:4
- Other concrete 1:3:6
- Waterproof concrete Add salt
- No chemicals
- No SCMs
- Precision was ugly
- Bulking made it worse
Proportioning Approaches Present

• ACI 211
  • Last revised in 1991
  • Linear
• Developed
  • Before water reducers
  • Before supplementary cementitious materials
• Primarily focused on structural concrete
  • 100 mm (4”) slump
  • 30 MPa (~4000 psi)
Preconceptions

- More cement = more strength
- Strength is everything
- Slump indicates quality
- Gradations of individual fractions are critical
What do we need?

- Transport properties (everywhere)
- Aggregate stability (everywhere)
- Strength (everywhere)
- Cold weather resistance (cold locations)
- Shrinkage (dry locations)
- Workability (everywhere)
Proportioning

Filler
Gradation

Glue
What sort
How much
How do we proportion to achieve design goals?

<table>
<thead>
<tr>
<th></th>
<th>Workability</th>
<th>Transport</th>
<th>Strength</th>
<th>Cold weather</th>
<th>Shrinkage</th>
<th>Aggregate stability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aggregate System</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type, gradation</td>
<td>✔ ✔</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>✔ ✔</td>
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<tr>
<td>Paste quality</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air, w/cm, SCM type and dose</td>
<td>✔ ✔ ✔ ✔ ✔ ✔</td>
<td>✔ ✔ ✔ ✔ ✔</td>
<td>✔ ✔ ✔ ✔ ✔</td>
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<td>✔ ✔ ✔ ✔ ✔</td>
<td>✔ ✔ ✔ ✔ ✔</td>
</tr>
<tr>
<td>Paste quantity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vp/Vv</td>
<td>✔ ✔</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>✔ ✔</td>
</tr>
</tbody>
</table>
Step 1 Paste Quality

- Binder type
  - Cement type
  - SCM type and dosage
- w/cm
  - ~0.38-0.42
- Air void system
  - <0.2 SAM
  - <0.008 in. spacing factor
  - >5% in place
  - Stable
Step 2 Aggregate system

- Choices...
  - 2 bins or 3?
  - ASTM C33
  - Or combined:
    - Haystack
    - Shilstone Plot
    - Power 45

- Tarantula
Step 2 Aggregate system

- Tarantula Curve

![Tarantula Curve Diagram]

Greater than 15\% on the sum of #8, #16 and #30
24-34\% of fine sand (#30-200)
Step 2 Aggregate system

• Choose an aggregate system…
Step 3 Paste Content
Step 3 Paste Content
Step 3 Paste Content
Workability

![Workability Diagram](image-url)
Strength

![Graph showing compressive strength vs. cement content for w/c = 0.35](image)

- Compressive Strength, psi
- Cement Content, pcy
Air Permeability

![Graph showing air permeability index vs cement content with w/c = 0.35. The graph displays the permeability index at different curing times: 1-day, 3-day, and 28-day. Each curing time has a different symbol: blue diamonds for 1-day, red squares for 3-day, and green triangles for 28-day. The x-axis represents cement content in pcy, ranging from 400 to 750, and the y-axis represents the air permeability index on a log scale, ranging from 10.8 to 13.0.]
Rapid Chloride Penetration

![Graph showing rapid chloride penetration](image-url)
Shrinkage
Step 3 Paste Content

- Need a minimum paste for workability
- Excess has a:
  - Small negative effect on strength
  - Negative effect on permeability, shrinkage, cost
  - Negative effect on heat
- “Optimum” depends on:
  - Aggregate type
  - Gradation
  - Binder type
- Typically Vv ~125-200%
Doing the Sums

The wonders of a spreadsheet and a solver function…
## Doing the Sums

The wonders of a spreadsheet...

<table>
<thead>
<tr>
<th>Materials</th>
<th>Targets</th>
<th>R.D.</th>
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</thead>
<tbody>
<tr>
<td>Cement</td>
<td>Type I</td>
<td>3.15</td>
</tr>
<tr>
<td>SCM 1</td>
<td>F Ash</td>
<td>2.65</td>
</tr>
<tr>
<td>SCM 2</td>
<td>Slag</td>
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<tr>
<td>Coarse Agg</td>
<td>A85906</td>
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<tr>
<td>Fine Agg</td>
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<tr>
<td>Intermediate</td>
<td>A85007</td>
<td>2.43</td>
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<tr>
<td>Water</td>
<td></td>
<td>1.00</td>
</tr>
</tbody>
</table>

### Paste Quality

<table>
<thead>
<tr>
<th>Project</th>
<th>Gravel 1”</th>
<th>5/15/2017</th>
</tr>
</thead>
</table>

| Cementitious | 428 | pey |
| w/cm        | 0.42 |
| Air %       | 5.0 | %   |
| % SCM 1     | 20  | %   |
| % SCM 2     | 0   | %   |
| Voids in aggregate | 25.3 | % |
| Required Vp/Vv | 125  | % |

| Strength | 4000 psi | 7 days |
| RCP      | 1500 coulomb | 56 days |
| Wenner   | 27 kΩ-cm | 28 days |
The wonders of a spreadsheet...

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<th>Mixture Proportions</th>
<th>Targets</th>
<th>Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pounds</td>
<td>R.D.</td>
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<tr>
<td>Cement Type 1</td>
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<tr>
<td>SCM 1 F Ash</td>
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<td>2.65</td>
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<tr>
<td>SCM 2 Slag</td>
<td>0</td>
<td>1.00</td>
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<tr>
<td>Course Agg A85005</td>
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<tr>
<td>Fine Agg A25518</td>
<td>1318</td>
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<td>Intermediate A85007</td>
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<tr>
<td>Water</td>
<td>180</td>
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<tr>
<td>Air %</td>
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</tr>
<tr>
<td></td>
<td>4019</td>
<td>27.00</td>
</tr>
</tbody>
</table>

- **Targets**
- **Actual**

**Additional Values**

- Cementitious: 428, 428 pcy
- Volume of paste: 24.0 %
- Volume of aggregates: 76.0 %
- Volume of voids: 19.2
- VP/VC: 125, 125.0
- w/cm: 0.42, 0.42
- % SCM 1: 20, 20 %
- % SCM 2: 0, 0 %
- Mass aggs: 3411, 3411 pcy
- Excess paste, %: 4.8 %
Trial Batches

- Workability
- Air void system
- Setting
- Strength gain
- Permeability
So

• It's all about the water…
  • The right amount
  • At the right time

Concrete and Water

• At mixing – less water is better
• After setting – more water is better
• Later on – less water is better
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<td>Successful paving in desert environments requires attention to key construction processes. Pavement condition data indicates excellent performance in desert environments. Angel Mateos, UCPRC; Dave Rath, Southwest Concrete Paving Company; and Matt Fonte, Fonte &amp; Company</td>
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