**Goal**

- To have consistent quality concrete provided to VDOT
- Pay based on the quality of concrete

---

**Differences in Specifications**

<table>
<thead>
<tr>
<th>Item</th>
<th>Current</th>
<th>ERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mix Design</td>
<td>Prescriptive</td>
<td>Performance Measures</td>
</tr>
<tr>
<td>Testing</td>
<td>VDOT</td>
<td>Contractor and VDOT</td>
</tr>
<tr>
<td>Basis of Pay</td>
<td>Minimum</td>
<td>PWL</td>
</tr>
</tbody>
</table>

---

**ERS**

Includes
- QC Plan by the Contractor
  - Applicable to preconstruction and during construction
- Mix design approval
- Acceptance

---

**Sampling and Testing (Acceptance)**

- After 2 ft³ is discharged
- Screening tests: every load by the Contractor (air content, slump, unit weight, temperature)
- Pay factor tests: randomly one per subplot by VDOT (strength and permeability, PWL)

---

**Statistics is a tool used in QA**

Statistics is the science that deals with the treatment and analysis of numerical data
Variability

- **Variability** – everything varies
- **Variability** can be controlled, but cannot be eliminated. Each material and process has some inherent variability
- Assignable variability can be reduced IF we identify the cause

QC/QA and Variability

\[ \text{variability} + \text{variability} + \text{variability} + \text{Variability} \]

\[ S^2 = S^2_s + S^2_t + S^2_m + S^2_c \]

Ideal World

\[ S^2 = S^2_s + S^2_t + S^2_m + S^2_c \]

In Real World try to minimize \( S^2_s + S^2_t \)

Material and construction variability

- **Material variability** is due to the random variation that naturally exists in a given material.
- **Construction variability** is the result of variation that is inherent in the production and construction methods.
- In the ERS, currently the Material Variability is measured and the Construction variability is being studied.

Nature avoids absolutes – variation is the rule.

Scientific Tools to Use in the Treatment and Analysis of Variability

- **Statistics**
- **Random sampling**

Population (A set of units)

147 units or elements
Sample from the Population or Lot (A subset of the units of a population)

From each sample:
- Strength
- Permeability
- Slump, Air, Temp
- Unit Weight

Approximate Areas

<table>
<thead>
<tr>
<th>Deviation from Mean</th>
<th>Area Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean ± 1 Standard Dev</td>
<td>68.2% of Area</td>
</tr>
<tr>
<td>Mean ± 2 Standard Dev</td>
<td>95.4% of Area</td>
</tr>
<tr>
<td>Mean ± 3 Standard Dev</td>
<td>99.8% of Area</td>
</tr>
</tbody>
</table>

Normal Distribution

Basically, the...is a bell-shaped curve.

\[
y = \frac{1}{\sigma \sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}
\]

Same Mean – Different Distribution, Which one do you want?

Compressive Strength (Thousands) psi

Different Mean – Different Distribution, Which one do you want?

Compressive Strength (Thousands) psi

Estimating PWL

- Compressive strength
  \[Q_s = (\text{Average} - \text{LSL})/s\]
- Permeability
  \[Q_u = (\text{USL} - \text{Average})/s\]

Q is the Quality Index, used to estimate PWL (percent within limits) from Tables

LSL: lower specification limit
USL: upper specification limit
s: sample standard deviation
Pay Factor

- PWL for strength and permeability:
  \[ PF = 82 + 0.2 \times \text{PWL} \]
  100% pay for PWL = 90%
- Average pay factor:
  \[ C_1(\text{Perm}) + C_2(\text{Str})/(C_1 + C_2) \]
  \( C \) is a weighting factor
- Total pay factor = Avg pay factor times unit bid price plus the additional price adjustment for deficient thickness (pavement) and incentive or disincentive for the ride quality.

Intent

- In the selection of LSL or USL the intent is to match the average quality of concretes delivered to VDOT over the years
- Relationship between \( f'_c \) and LSL sought
- Variability is included to ensure uniform consistent product

Selection of LSL

Example 1

- Average of 3 tests=5000 psi
- Standard Deviation=338 psi
- \( f'_c \) is 4000 and LSL 4500 for deck
- \( Q=(5000-4500)/338=1.48 \)
- PWL from Table=100%
- \( PF = 82+0.2(100)=102 \)

Example 2

- Average of 3 tests=5000 psi
- Standard Deviation=600 psi (higher variability than Example 1)
- \( f'_c \) is 4000 and LSL 4500 for deck
- \( Q=(5000-4500)/600=0.83 \)
- PWL from Table=75.53 %
- \( PF = 82+0.2(75.53)=97.11 \)

Example 3

- Average of 3 tests=5160 psi (higher than Example 2)
- Standard Deviation=600 psi
- \( f'_c \) is 4000 and LSL 4500 for deck
- \( Q=(5160-4500)/600=1.10 \)
- PWL from Table=90.16 %
- \( PF = 82+0.2(90.16)=100.03 \)
First Pilot Projects

Salem:
- Route 11 over the New River and Norfolk Southern Railroad tracks near Radford University

Culpeper:
- Route 28 near Manassas

Salem Mix Proportions

<table>
<thead>
<tr>
<th>Material</th>
<th>Amount (lb/yc³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement Type I/II</td>
<td>318</td>
</tr>
<tr>
<td>Fly ash Class F</td>
<td>159</td>
</tr>
<tr>
<td>Slag</td>
<td>159</td>
</tr>
<tr>
<td>Fine aggregate</td>
<td>1101</td>
</tr>
<tr>
<td>Coarse aggregate</td>
<td>1755</td>
</tr>
<tr>
<td>w/cm</td>
<td>0.45</td>
</tr>
</tbody>
</table>

Salem Strength and Permeability

<table>
<thead>
<tr>
<th></th>
<th>Average (psi)</th>
<th>Std Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strength</td>
<td>5016</td>
<td>305</td>
</tr>
<tr>
<td>Permeability</td>
<td>391</td>
<td>72</td>
</tr>
</tbody>
</table>

N=31

Proposed Projects

Each District will incorporate the ERS on two (preferred) of the following projects that will be advertised from 10/06 to 7/07

ERS Projects

<table>
<thead>
<tr>
<th>DISTRICT</th>
<th>PROJECT</th>
<th>ADVERTISEMENT DATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bristol</td>
<td>PM07-004-195,031</td>
<td>December 12, 2006</td>
</tr>
<tr>
<td>Culpeper</td>
<td>To Be determined</td>
<td></td>
</tr>
<tr>
<td>Fredericksburg</td>
<td>Sta. 3 over St. &amp; S. Springfield Co</td>
<td>June 2007</td>
</tr>
<tr>
<td></td>
<td>Sta. 3 over Petersburg River - Mathews</td>
<td>September 2006</td>
</tr>
<tr>
<td></td>
<td>Sta. 34 over Cat Point Creek - Richmond</td>
<td>December 2006</td>
</tr>
<tr>
<td>Hampton Roads</td>
<td>RT. 175 - Chincoteague</td>
<td>August 2006</td>
</tr>
<tr>
<td>Lynchburg</td>
<td>RT. 7 - Bridge over Core Creek 365</td>
<td>February 13, 2007</td>
</tr>
<tr>
<td>Northern Virginia</td>
<td>RT. 1 Bridge replacement at Weyers Creek 1942</td>
<td>March 9, 2007</td>
</tr>
<tr>
<td></td>
<td>140 - Fourth Lane</td>
<td>November 27, 2006</td>
</tr>
<tr>
<td>Richmond</td>
<td>RT. 2 over Chickahominy</td>
<td>August 2006</td>
</tr>
<tr>
<td>Saugus</td>
<td>RT. 123 Bridge over Nantucket Creek 51819</td>
<td>February 2, 2006</td>
</tr>
<tr>
<td>Dayton</td>
<td>State Route 4 Bridge replacement 000412</td>
<td>October 20, 2006</td>
</tr>
<tr>
<td></td>
<td>RT. 240 Bridge at Jeremy's Run 11091</td>
<td>April 19, 2007</td>
</tr>
</tbody>
</table>

Concern

- How to resolve disagreement between the producer and the contractor concerning defects (scaling, cracking, lack of air) in the structure.
- VDOT deals with the Contractor. Producer and contractor must solve issues between each other. ERS will help since it will ensure that the concrete supplied meets the specs! 
Concern

• Too many samples!
• Basically we are following the frequency used currently. However, testing more samples minimizes uncertainty.

Concern

• VDOT will not get bids or it will be very high!
• Did not happen.
  – Rte 5: price was not high!
  – Rte 624: had bids.
  – Rte 175: a plant will be set

Concern

• Only those with uniform and consistent product will benefit!
• That is the goal. All producers will be knowledgeable about their material.

Concern

• Penalty!
• Quality control prior to construction will ensure that acceptable product is delivered to the jobsite. Thus, penalty should not be an issue!

Concern

• Small producers will not be able to compete or produce considering the cost of testing.
• Small producers will also benefit from quality control. They will not waste material since they will be in control of their process.

Next Steps

• Projects selected by districts to be used with out pay factor (PWL)
• Monitor pilot projects and collect data
• Resolve issues with stake holders
• Modify the ERS special provisions
## Industry Trend

- NRMCA promotes P2P
  - Prequalification
  - Identity testing