Coarseness - Workability - Consolidation
A New Approach

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Outline

• Introduction of OG concrete
• The Box Test
• A new path forward
What is OG concrete all about?

• The goal of OG concrete is to **increase** the volume of **aggregate** and **decrease** the volume of **paste**
• paste = binder + water + air
• The paste is the most costly, least sustainable concrete ingredient and has the biggest impact on the durability
Concrete
Aggregate
Paste

Measured Shrinkage

Drying Time

After Weiss

Optimized Graded Concrete

Concrete

Paste

Aggregate
How do you design optimized graded concrete?

- Find your aggregate gradation
- Find out the volume and consistency of the paste that you need for your application
- Check strength and durability

_after Koehler and Fowler_
How do you find your gradation?

- Shilstone
- 8-18 curves
- Power 45

Which one is right?
What do these tools tell you?
Is one better than the other?
Shilstone

Workability Factor (WF) = % passing #8 + 2.5x powder above 6 sacks

Coarsness Factor (CF) = \( \frac{\% \text{ cumulative retained 3/8"}}{\% \text{ cumulative retained #8}} \)
Typical Individual Percent Retained

Max Boundary
Min Boundary

Fine Aggregate
Intermediate
Coarse Aggregate

18%
8%

% Retained

Sieve No. #200 #100 #50 #30 #16 #8 #4 3/8" 1/2" 3/4" 1" 1.5"
Research Goals

• Find gradations that allow reduced paste content while still providing sufficiently workable concrete for paving.

• We need "enough" workability to make the concrete place able by the paver but not too much that it doesn't hold an edge.

• The slump cone can not tell us this
What part of a paver is the most critical for concrete consolidation?
• We want a test that is simple and can examine:
  – Response to vibration
  – Filling ability of the grout (avoid internal voids)
  – Ability of the slip formed concrete to hold a sharp edge (cohesiveness)
Box Test

- Add 9.5” of unconsolidated concrete to the box
- A 1” diameter stinger vibrator is inserted into the center of the box over a three count and then removed over a three count
- The edges of the box are then removed and inspected for honey combing or edge slumping
# Box Test Ranking Scale

<table>
<thead>
<tr>
<th></th>
<th>4</th>
<th></th>
<th>3</th>
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<tbody>
<tr>
<td></td>
<td>Over 50% overall surface voids.</td>
<td></td>
<td>30-50% overall surface voids.</td>
</tr>
<tr>
<td>2</td>
<td>10-30% overall surface voids.</td>
<td></td>
<td>Less than 10% overall surface voids.</td>
</tr>
<tr>
<td>1</td>
<td>Less than 10% overall surface voids.</td>
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Edge Slumping

Bottom Edge Slumping  Top Edge Slumping
Question:
Why does a mixture fail the box test?
Question:

Why does a mixture fail the box test?

Answer: it either needs more paste or more lubrication (plastic yield stress is too large)
Question:

What if we found out how much water reducer it took to pass the box test without changing the paste content?
Question:

What if we found out how much water reducer it took to pass the box test without changing the paste content?

Answer: This would allow us to measure how aggregate gradation impacts the workability of a mixture.
Mix Concrete

Conduct: Slump, Unit Weight, Air, and Box Test

Did it Pass the Box Test?

Put Material from slump and box test into mixer. Discard Air test Material

Add WR and Remix

Conduct: Slump, Unit Weight, and Box Test.

Was WR added?

Yes

Conduct Air

No

Make Cylinders
Validation

• Test was found to be accurate to +/- 2 oz/cwt with a single operator.
• Same box test performance was found if the WR was added up front or if added in small dosages
• If the sample did not pass the box test within one hour it was discarded
• The box test has correlated well with field paving mixes
• Work is ongoing with multiple operators
Summary of the Box Test

• The box test evaluates the response of a concrete mixture to vibration.
• We did this because no other test exists that can tell us this information.
Use of the Box Test to Evaluate Shilstone

- 0.45 w/cm
- 20 percent fly ash replacement
- A single sand source—Sand A
- Used 3 crushed limestones
  - Limestone A
  - Limestone B
  - Limestone C
Aggregate Summary

Limestone A

Limestone B

Limestone C

Sand A
60/40 blend by volume
5 Sack Limestone B & Sand A

- Middle of Shilstone
- Bottom of Shilstone
- 60%CA, 40%FA
- Left of Shilstone
- Min Boundary
- Max Boundary

Sieve No.

% Retained

0% 5% 10% 15% 20% 25% 30% 35%

#200 #100 #50 #30 #16 #8 #4 3/8" 1/2" 3/4" 1" 1.5"
5 Sack Limestone C & Sand A

- Middle of Shilstone
- Bottom of Shilstone
- Left of Shilstone
- Min Boundary
- Max Boundary

Sieve No.: #200, #100, #50, #30, #16, #8, #4, 3/8", 1/2", 3/4", 1", 1.5"

% Retained:
- 0.86
- 0
- 0

Graph showing the distribution of different sizes of sieves for Middle of Shilstone, Bottom of Shilstone, and Left of Shilstone, with Min and Max boundaries.
Using the Shilstone Chart alone to proportion your aggregates does not influence performance with these materials.

The 8-18 chart seems to provide better guidance.
Does Distribution Really Matter?

Sieve No.

Limestone C-Middle of Shilstone
Limestone A- Middle of Shilstone
Min Boundary
Max Boundary

% Retained

0% 10% 15% 20% 25% 30% 35%

#200 #100 #50 #30 #16 #8 #4 3/8" 1/2" 3/4" 1" 1.5"
We sieved Limestone A to have the exact same gradation as Limestone B.
Yes, Distribution Matters!

- Limestone C
- Limestone A
- Min Boundary
- Max Boundary

Sieve No.

% Retained
By changing the distribution of aggregates, it changes the workability of the mixture. However the Shilstone method did not accurately predict this (at least for these aggregate combinations).
Proportioning of Coarse to Intermediate
Proportioning of Coarse to Intermediate

Sieve No. vs % Retained

- Min Boundary
- Max Boundary
- CF=70, WF=30
- CF=75, WF=30
- CF=65, WF=30
- CF=60, WF=30
- CF=55, WF=30
- CF=80, WF=30
- CF=50, WF=30
- CF=45, WF=30

Sieve No.: #200, #100, #50, #30, #16, #8, #4, 3/8", 1/2", 3/4", 1", 1.5"
Proportioning of Sand

- Sieve No.: #200, #100, #50, #30, #16, #8, #4, 3/8", 1/2", 3/4", 1", 1.5"
- % Retained:
  - Min Boundary: 9.9, 6.0, 11.6, 19.1, 40.4
  - Max Boundary: 3/8", 1/2", 3/4", 1", 1.5"
- CF: 70, WF: 25, 30, 35, 40, 45

Graph showing the proportioning of sand with different boundary conditions and CF, WF ratios.
Proportioning of Sand

Min Boundary
Max Boundary
CF=70,WF=30
CF=70,WF=25
CF=70,WF=40
CF=70,WF=35
CF=70,WF=45

% Retained

Sieve No.

0% 5% 10% 15% 20% 25%
Impacts of a Single Valley

Min Boundary
Max Boundary

CF=65, WF=30

Sieve No.

% Retained

#200 #100 #50 #30 #16 #8 #4 0.375 0.5 0.75 1 1.5

4.3
Impacts of a Single Valley

- Min Boundary
- Max Boundary
- CF=65, WF=30
- No 3/8 Valley

Sieve No.

% Retained

% Retained

0% 5% 10% 15% 20% 25% 30%

2.4 4.3
Impacts of a Single Valley

- Min Boundary
- Max Boundary
- CF=65, WF=30
- No 3/8"
- No 3/8 Valley

Sieve No.  

% Retained

0%  5%  10%  15%  20%  25%  30%

0  0.375  0.5  0.75  1  1.5

2.4  4.3  3.4
Excessive amount of sand, this creates workability issues.

Insufficient amount of sand to create mortar.

Decreasing workability issues normally associated with manufactured sands.

No performance issue.

Reduces edge slumping.

Excessive amount of aggregate that decreases workability.

More research needs to be conducted to find the limit.
Conclusion

• The box test has shown to be a useful tool to understand the impact of gradation on the workability of mixtures for concrete pavements
• The Shilstone box was not shown to be a useful method for the materials investigated
Conclusion

• A modified version of the 8-18 graph was shown to better predict performance.
• The box test has been used to evaluate the performance of pavement concrete mixtures and a recommended gradation limit has been produced.
Questions?

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