Measuring the Water Content in Fresh Concrete

Tyler Ley, PE, Ph.D.
Bret Robertson, PE
Acknowledgements

FHWA Mobile Concrete Trailer
Jagan Gudimetta
Jim Grove
John Anderson
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Oklahoma DOT
Kenny Seward
Matt Romero
Walt Peters
Background

Why is this important?
Current methods

*The Phoenix!*
Why is the w/cm important?

• As you increase water in a mix then you increase the spacing between the cement grains.

• This dilutes the mixture.
Why is the w/cm important?

• Determines your strength and permeability.

• Consistency

• We need a reliable field test to measure this.
Why is the water content off?

• Incorrect aggregate moisture content
• Batch plant tolerance
• Wrong amount is added
• Renegade Water!
What is Renegade Water?
What is Renegade Water?
What is Renegade Water?

Water not recorded on the batch ticket -
• In the drum from previous mix
• Added to concrete in transit or on site
• etc

Oklahoma’s finest
Microwave Oven – AASHTO T 318

• Collect 1500 g of concrete
• Weigh sample
• Evaporate water
• Weigh sample
• Compare to cement content in the mix and determine w/cm

• Sounds simple, right?
Challenges with microwave oven test

- ≈40 min in length
- Labor intensive
- Results are variable (+/- 0.05 w/cm)
You have to keep opening the bag and breaking up the concrete every few minutes.
Challenges with microwave oven test

• Results are variable +/- 0.05 w/cm

Amount required in the test

1500 g
≈1/3 of 4x8 cylinder
How can we improve the microwave oven method?

• Increase sample size
• Remove technician labor
• Decrease time
• Use the batch ticket
Steps

• Record batch ticket and aggregate properties
• Make and weigh 4x8 cylinder
• Dump cylinder into pan and weigh
• Start test
• Come back when finished
• Weigh pan
We call this test “The Phoenix”!!!
Change in mass over time

Fresh concrete is added here

ALL Water is gone!
Change in mass over time

Fresh concrete is added here

The test removes the water from the paste and aggregate!!!!

ALL Water is gone!
The Phoenix removes all the water!!!

- If we know the absorption capacity of the aggregate then we can remove this from the total water content and get the w/cm

- This assumes that during mixing the moisture content of the aggregate will become SSD
How do you get w/cm?

• The change in mass before and after cooking = amount of water in the cylinder

• Calculate how much water will be in aggregate after reaching SSD and remove that from the total water
How do you get w/cm?

• Use the batch ticket information to find the amount of binder within the cylinder

• Make a correction based on the measured cylinder unit weight versus the theoretical unit weight to correct for air
There is an app for that!!!
How can we test it?

• Make mixtures in the lab where we carefully control the moisture contents and batch weights.

• We should know the w/cm very accurately.

• Measure the w/cm with the Phoenix and compare.
Mix Information

• 9 Sources of Coarse Aggregate
  • Granites, River Rock, and Limestones

• 3 Sources of Fine Aggregate
  • Natural sands and Manufactured sand

• Specific Gravities: 2.42-2.75

• Absorptions (%): 0.46-4.69

• Five different w/cm

• Different paste contents
9 Coarse Agg
3 Fine Agg
5 Different w/cm
228 Tests
COV = 3%

Line of equality

Measured w/cm

Batched w/cm

(+ 0.02 w/cm)

(- 0.02 w/cm)

27 Tests
23 Tests
130 Tests
31 Tests
Lab Data

9 Coarse Agg
3 Fine Agg
5 Different w/cm
228 Tests
COV = 3%

Measured w/cm

Batched w/cm

Line of equality

Microwave Oven Test

(+0.02 w/cm)

(-0.02 w/cm)

27 Tests
23 Tests
130 Tests
31 Tests
6 Tests
Lab Data

Line of equality

(+) 0.02 w/cm

(-) 0.02 w/cm

Measured w/cm

Batched w/cm

Granite 1
Granite 2
Granite 3
Granite 4
Limestone 1
Limestone 2
Limestone 3
River Rock 1
River Rock 2
<table>
<thead>
<tr>
<th>Aggregate Type</th>
<th>Size</th>
<th>SpG</th>
<th>Abs (%)</th>
<th>State</th>
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</thead>
<tbody>
<tr>
<td>Granite 1</td>
<td>Coarse</td>
<td>2.75</td>
<td>0.46</td>
<td>OK</td>
</tr>
<tr>
<td>Granite 2</td>
<td>Coarse</td>
<td>2.75</td>
<td>0.51</td>
<td>GA</td>
</tr>
<tr>
<td>Granite 3</td>
<td>Coarse</td>
<td>2.59</td>
<td>1.06</td>
<td>MN</td>
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<tr>
<td>Granite 4</td>
<td>Coarse</td>
<td>2.66</td>
<td>0.66</td>
<td>MN</td>
</tr>
<tr>
<td>Limestone 1</td>
<td>Coarse</td>
<td>2.42</td>
<td>4.69</td>
<td>IA</td>
</tr>
<tr>
<td>Limestone 2</td>
<td>Coarse</td>
<td>2.67</td>
<td>0.70</td>
<td>OK</td>
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<td>Limestone 3</td>
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<td>OK</td>
</tr>
<tr>
<td>River Rock 1</td>
<td>Coarse</td>
<td>2.67</td>
<td>1.52</td>
<td>MN</td>
</tr>
<tr>
<td>River Rock 2</td>
<td>Coarse</td>
<td>2.68</td>
<td>0.81</td>
<td>MN</td>
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<tr>
<td>Natural Sand 1</td>
<td>Fine</td>
<td>2.62</td>
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<td>OK</td>
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<td>Natural Sand 2</td>
<td>Fine</td>
<td>2.61</td>
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<tr>
<td>Man Sand</td>
<td>Fine</td>
<td>2.76</td>
<td>1.05</td>
<td>OK</td>
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</table>
Discussion

• All lab mixes are within +/- 0.02 w/cm with most of them within +/- 0.01 w/cm.

• The COV is < 3%!!!

• What about the field?
How can we test in the field?

• Use the batch ticket information to determine design w/cm

• Measure w/cm with the Phoenix

• All testing was done at the batch plant
• Four different projects 27 different mixtures
• Paving, bridge decks, substructure
27 mixtures investigated
15% with w/cm > 0.02 than design
Discussion

• The Phoenix data looks promising

• 15% of mixtures had a w/cm > 0.02 than what was reported on the batch ticket.

• All testing was done at the batch plant.

• The producers knew we were coming.
How can the Phoenix help you?

• Tells you the water content at any point in the construction process < 12 min.

• Helps you produce very consistent concrete.

• Moisture corrections or absorption capacity for aggregates in < 3 min.

• Bench mark that a plant is operating correctly

• Training tool for operators
I need your help!!!

• I need people willing to try a Phoenix in the field and collect data and provide feedback.

• Would AASHTO COMP be willing to support a new test method?
Contact me if you are interested in taking a ride on the Phoenix!!!
Conclusion

• Beware Renegade Water!!!
• Test methods are needed to measure the water content of fresh concrete
• The Phoenix is a new test method with +/- 0.01 w/cm accuracy and COV = 3% for over 228 lab tests.
Questions???
Tyler.ley@okstate.edu
www.tylerley.com
Sample Size Comparison

• 3 mixes
  • 0.45 w/cm; No admixes, 6.5 sacks
  • Tested UW with 4 different size cylinders
    • 3 cylinders for each size

Table 1. Multiple size volumes tested for three, 0.45 w/cm mixtures.

<table>
<thead>
<tr>
<th>Number Of Samples</th>
<th>Sample Volume (ft$^3$)</th>
<th>Average Density (lb/ft$^3$)</th>
<th>Standard Deviation (lb/ ft$^3$)</th>
<th>Average Measured w/cm</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>0.02</td>
<td>150.6</td>
<td>3.2</td>
<td>0.42</td>
<td>0.022</td>
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<tr>
<td>9</td>
<td>0.03</td>
<td>150.5</td>
<td>1.4</td>
<td>0.44</td>
<td>0.021</td>
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<tr>
<td>9</td>
<td>0.06</td>
<td>151.6</td>
<td>0.3</td>
<td>0.45</td>
<td>0.010</td>
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<tr>
<td>9</td>
<td>0.07</td>
<td>151.6</td>
<td>0.5</td>
<td>0.45</td>
<td>0.010</td>
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<tr>
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<td>0.20</td>
<td>151.0</td>
<td>0.7</td>
<td>0.44</td>
<td>0.011</td>
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<tr>
<td>9</td>
<td>0.25</td>
<td>151.3</td>
<td>0.5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Have you ever been penalized for low strength?

• Low strengths is typically caused by poor cylinder handling.

• Our industry puts so much emphasis on strength because it is easy to measure.

• If you can verify air and w/cm on site then the strength will come.
How many ways can extra water get in our mix?

1. Moisture contents of aggregate
2. Batching tolerances
3. Water in drum during batching
4. Batching Tolerances
5. Added during transit or on site
Aggregates in stockpiles can have a variety of moisture contents.

Aggregates after mixing and hauling = SSD.
The Phoenix removes all the water!!!

• This means we need to know how much water is in the aggregate so that we can subtract that from the total water to find what is in the paste.
How much does this really impact strength?

ACI 211
How much does this really impact strength?

\[ 0.01 \text{ w/cm} \quad 150 \text{ psi} \]
How much does this really impact durability?

Fluid penetration is important for most durability mechanisms.

Let’s focus on corrosion and use Life365 software to model this.

Be careful with service life models!
How much does this really impact durability?

Bridge Deck in Oklahoma

2” of cover
How much does this really impact durability?

Bridge Deck in Oklahoma
2” of cover

.01 w/cm
1 year
What about consistency?

Water plays a key role in the consistency of your concrete.

1 gallon/yard = 1” slump
How much extra water matters?

For 8 cubic yards of a 6 sack mix

5 gallons =  +0.01 w/cm
          -150 psi
          -1 yr service life
          +1” slump
Is there a way to measure this?

• Slump
• Minnesota DOT Method
• Electrical Methods
• Microwave Oven
Does the slump tell me how much water is in my mix?

Slump is a measure of consistency.

Mixtures can be rejected because the slump is too high.

Does this mean the water is off?
The water content is constant but the aggregate gradation is not just right...

Deficient Fine Sand

Excessive fine sand

High Intermediate

High Coarse
Minnesota DOT Method

- Moisture content of aggregates at plant are tested
- Dump trucks are used for placement
- No water in the truck before concrete
- No water added in route or onsite
- The batched w/cm doesn’t change
- This only works for paving mixtures
Electrical Methods

• An electrical signal current is sent between at least two probes.
• The movement of electrons through the concrete is characterized.
• Correlate this to w/cm.
Challenges

The following items impact the measurement:

• Aggregate size
• Aggregate volume
• Temperature
• Admixture type and dosage
• Paste content
• SCM volume
• Values change over time
• Water content
Challenges

The following items impact the measurement:
• Aggregate size
• Aggregate volume
• Temperature
• Admixture type and dosage
• Paste content
• SCM volume
• Values change over time
• Water content

Only one of these have to do with water!!!!
Discussion

• The industry needs a test that can measure the water content in fresh concrete.

• The existing tests give us some information but they all have a major flaw.

• The microwave oven test shows the most potential.
Rejecting because of Slump

- Max slump spec = 7” for a pier “to control w/cm”
- Concrete was rejected but w/cm was measured on site to be within specified range

<table>
<thead>
<tr>
<th>Truck Number</th>
<th>Average Measured w/cm</th>
<th>Specified w/cm</th>
<th>Slump (in)</th>
<th>Specified Slump (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Truck 6</td>
<td>0.47</td>
<td>0.25-0.48</td>
<td>9.00</td>
<td>7.00</td>
</tr>
<tr>
<td>Truck 7</td>
<td>0.42</td>
<td>0.25-0.48</td>
<td>8.00</td>
<td>7.00</td>
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