Concrete Testing: Experience and Advise from a World Traveling Concrete Consultant

Luke M. Snell, P.E., FACI
Concrete Consultant
Edwardsville, IL

PROBLEMS WITH CONCRETE

1. People Not Educated
2. Consolidating Concretes
3. Metal locator - Using Equipment without Calibration
4. NDT and Coring issues

MUST PEOPLE STARTING IN OUR INDUSTRY

1. Do not understand how concrete works
2. Need to educate them on the basics
3. An educated work force needs to know what is important and why they are following procedures and specifications

USE THE PORCUPINE TO EXPLAIN HOW CEMENT AND CONCRETE WORKS

Using “Porcupine Balls” to Explain Hydration and Curing
The amount of water we added to the concrete mixture determines what we must do in curing.

Approximate Time To Close Capillary Pores

<table>
<thead>
<tr>
<th>w/cm Ratio</th>
<th>Time - days</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.40</td>
<td>3</td>
</tr>
<tr>
<td>0.45</td>
<td>7</td>
</tr>
<tr>
<td>0.50</td>
<td>14</td>
</tr>
<tr>
<td>0.60</td>
<td>180</td>
</tr>
<tr>
<td>0.70</td>
<td>360</td>
</tr>
<tr>
<td>over 0.70</td>
<td>impossible</td>
</tr>
</tbody>
</table>

Curing with Plastic

STEAM CURING
Our Goal
Provide a good curing environment

➢ Temp above 40 F (5 C)
➢ Moisture in Concrete

Effects of Moisture
The strength of concrete and hydration depends on understanding the “finger theory” or the “porcupine” theory.

Consolidating Concrete

The owner rejected this precast concrete.
This bridge pier cost over $100,000 in investigations and repairs

Huge delays while contractor had to repair

CONTRACTOR MAY HAVE TO REPLACE!

What do all these have in Common?

Poor Vibration Techniques

This person is critical to the success of your project!
They need to be well trained on how to vibrate concrete!

Proper vibration techniques will:

1. Increase the compressive strength and bond between concrete and reinforcement
2. Decreases cold joints, honeycombing, and entrapped air
3. Causes concrete within a circular radius of action to “settle” and will remove excess entrapped air

Good Vibrations Will Eliminate

Honeycomb
Rock Pockets
Cold Joints
Reinforcements makes consolidation more difficult

May need to do extra consolidation at these places

Techniques of Vibrations

1. Vibrator straight/not cast at an angle

VERY POOR TECHNIQUE

Size of vibrator head determines spacing pattern

2. Radius of vibration about three(3) times diameter of vibrator

You must insert vibrator several times to consolidate the concrete when using small vibrators

3. Do not use the vibrator to move the concrete
Techniques of Vibrations

4. Insert Vibrator into the previous layer
   Recommend insertions at least 6" into previously placed concrete

5. Leave vibrator in concrete for 5-15 seconds
   Remove slowly

Vibration completed when:

1. Large aggregates disappear

Vibration completed when:

2. Concrete levels

Vibration completed when:

3. Air bubbles stop rising

Vibration completed when:

4. Thin film of water is evident on top of the concrete
Spacing Tips:

1. Watch the concrete surface to determine the area that is consolidated (radius of action)

Spacing Tips:

2. Space out the insertions of the vibrator so that all concrete is consolidated

Spacing Tips:

3. General Rule: The area (circle) that is consolidated three (3) times the vibrator's head diameter

Typical vibration pattern

Stop Vibrating when:

2. Large air bubbles stop coming to the surface

Stop Vibrating when:

1. The concrete surface takes on a sheen - concrete surface appears shiny
Stop Vibrating when:

3. You hear the sound of vibrator change pitch or tone

Vibrating Tips

1. Do not run the vibrator outside the concrete
   The vibrator will overheat and burn up
   The fresh concrete is necessary to cool the vibrator

2. Don’t start a job without a spare vibrator.

Vibrating Tips

3. Check vibrators to make sure it works

Remember, we can place concrete much faster than we can consolidate it!
Metal Locating Devices

Using equipment without Calibration

Various metal locating devices are available:

- Most are:
  - Expensive
  - Require trained personnel to operate

There are several inexpensive ones that appear to be easy to use. It still takes some time to learn how to use and understand its limitations.

NEED TO SET UP EXPERIMENTS

1. Learn how to use
2. The accuracy of the equipment
3. Limitations (what the equipment can't do)

EXPERIMENTS

Table 1: No. 4 (13 mm) steel reinforcement

<table>
<thead>
<tr>
<th>Measured clear cover Inches (mm)</th>
<th>Accuracy of horizontal location Inches (mm)</th>
<th>Instrumental reading of clear cover Inches (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1(25)</td>
<td>± 0.5 (± 12)</td>
<td>0.75(20)</td>
</tr>
<tr>
<td>2(50)</td>
<td>± 0.5 (± 12)</td>
<td>2(50)</td>
</tr>
<tr>
<td>3(75)</td>
<td>± 0.5 (± 12)</td>
<td>3(75)</td>
</tr>
<tr>
<td>4(100)</td>
<td>± 0.5 (± 12)</td>
<td>3.75(95)</td>
</tr>
<tr>
<td>5(125)</td>
<td>± 0.5 (± 12)</td>
<td>4.75(120)</td>
</tr>
<tr>
<td>6(150)</td>
<td>± 0.5 (± 12)</td>
<td>5.75(140)</td>
</tr>
</tbody>
</table>
**EXPERIMENT - RESULTS**

Table 2: No. 6 (19 mm) steel reinforcement

<table>
<thead>
<tr>
<th>Measured clear cover inches (mm)</th>
<th>Accuracy of horizontal location Inches (mm)</th>
<th>Instrumental reading of clear cover inches (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1(25)</td>
<td>± 0.5 (± 12)</td>
<td>1(25)</td>
</tr>
<tr>
<td>2(50)</td>
<td>± 0.5 (± 12)</td>
<td>2(50)</td>
</tr>
<tr>
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<td>± 0.5 (± 12)</td>
<td>3(75)</td>
</tr>
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<td>4(100)</td>
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<td>3.75(95)</td>
</tr>
<tr>
<td>5(125)</td>
<td>± 0.5 (± 12)</td>
<td>5(125)</td>
</tr>
<tr>
<td>6(150)</td>
<td>± 0.5 (± 12)</td>
<td>6(150)</td>
</tr>
</tbody>
</table>

**EXPERIMENT - RESULTS**

Table 3: No. 10 (32 mm) steel reinforcement

<table>
<thead>
<tr>
<th>Measured clear cover inches (mm)</th>
<th>Accuracy of horizontal location Inches (mm)</th>
<th>Instrumental reading of clear cover inches (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1(25)</td>
<td>± 0.5 (± 12)</td>
<td>0.5(12)</td>
</tr>
<tr>
<td>2(50)</td>
<td>± 0.5 (± 12)</td>
<td>1.75(45)</td>
</tr>
<tr>
<td>3(75)</td>
<td>± 0.5 (± 12)</td>
<td>2.75(75)</td>
</tr>
<tr>
<td>4(100)</td>
<td>± 0.5 (± 12)</td>
<td>3.75(95)</td>
</tr>
<tr>
<td>5(125)</td>
<td>± 0.5 (± 12)</td>
<td>4.5(115)</td>
</tr>
<tr>
<td>6(150)</td>
<td>± 0.5 (± 12)</td>
<td>5.5(140)</td>
</tr>
</tbody>
</table>

**LIMITATIONS**

- Discontinuous spots:
  - Short pieces of rebars
  - Nails or screws
- Need to remember the usual rebars placement practices

**FIELD STUDY - USA**

Experiments by Mongolian University of Science and Technology's Students

**FIELD STUDY - MONGOLIA**

- Discontinuous spots:
  - Short pieces of rebars
  - Nails or screws
- Need to remember the usual rebars placement practices
FIELD STUDIES - MONGOLIA

EVALUATION OF EQUIPMENT

Examples of evaluation

Metal locator with Ethiopian Students from Addis Ababa and Bahir Dar Universities

WHY STUDENTS FROM ETHIOPIA

• Students have English as a second language - a good evaluation of the instructions

• Students are not familiar with construction equipment - would not operate equipment by “feel”

STUDENTS REVIEWING DVD

Students using equipment on prepared samples #1

Students using equipment on prepared samples #2
FINDINGS #1

Students were able to use the equipment with only DVD instructions

No one reads the instructions!!!

FINDINGS #2

• Students were able to locate reinforcements in columns where the reinforcement spacing appeared to be logical

• The students gained confidence in using the equipment when the reinforcement spacings were known

FINDINGS #3

There is a need to train people so they have confidence in using the equipment - hands on training is critical

OTHER EXAMPLES OF EVALUATING EQUIPMENT (1)

Moisture meters in batch plant
1. Should be calibrated (rechecked) at least once a month

2. Batcher should continuously ask:
Is the moisture reading logical?
Does the batch make sense?
Recently involved with a plant that had not checked their moisture meters

Moisture meter indicated moisture of 10% on sand and 4% on rock (unlikely moisture values).

Strength issues resulted, owner rejected the concrete

Hours of meeting

Consultants to evaluate problem

Concessions on the amount of payment

Delay in payment

Loss of good will

Testing laboratory (Saudi Arabia) asked to evaluate a wall that was thought to have interior voids in the concrete

Brought a special piece of equipment (Impact echo) and was trained in Europe on how to use it.

Did 6 months of evaluating the concrete walls to find voids in the concrete

Developed a map of areas that they thought had voids

Did not check (open an area) that was thought to have voids.

When I was asked to evaluate the lab's results, I had them remove the concrete over where they said they had interior voids

After checking several areas, we found no interior voids

The owner had paid for 6 months of worthless testing

The problem could have been avoided if the testing laboratory had checked their results to make sure the equipment was giving them reliable results.
Investigating Concrete: When to use NDT, Coring

WHAT IS NDT?
- Measurement of a property that is easy to measure to estimate a property that is more difficult to determine
- Testing that does not destroy or physically damage the structure

WHY NDT IS NOT EXACT
- A. Concrete is non homogeneous
- B. Surface is dry, interior moist
- C. Equipment varies

REBOUND HAMMER
- Developed in 1948 by Swiss engineer - Ernst Schmidt
  Called:
  - Swiss Hammer
  - Schmidt Hammer
  - Concrete Test Hammer
  - Rebound Hammer
  - Surface Hardness Test
  - Impact Hammer
REBOUND HAMMER IS THE MOST POPULAR NDT METHOD

- Over 100,000 in use
- Cost $350 - $2500
- Can be bought on E-Bay

REBOUND HAMMER

Measures only surface hardness of concrete

NO THEORETICAL RELATIONSHIP BETWEEN REBOUND NUMBER AND COMPRESSIVE STRENGTH.

CONCEPT

Compare to golf ball bounce

Low number Soft surface Weak concrete

High number Hard surface Strong concrete
**Pressure Wave Techniques**

**REBOUND HAMMER (C 805)**
- Latch release
- Latch
- Case
- Hammer
- Scale
- Slider
- Spring
- Rod

**Read rebound**

**Hard spot**
- Soft spot
- Rough surface
- Hard layer

**PULSE VELOCITY - C 597**
- Transmitter
- Pulse
- Receiver
- Timer (Δt)

**STRENGTH CORRELATION**

\[
V = \text{constant} \times \sqrt[4]{E} \\
E \approx 57,000 \sqrt{f'c} \\
\rightarrow f'c \propto (V)^4
\]
**PROBLEMS: VOIDS**

Transmitter

Receiver

Electronics

**WATER FILLED VOID**

Transmitter

Receiver

Electronics

**CAN USE TO SOLVE PROBLEMS**

Use the Pythagorean Theorem

\[ C^2 = a^2 + b^2 \]

**PLACE TRANSUDER EQUAL DISTANCE ON EACH SIDE OF THE CRACK**

**DETERMINING CRACK DEPTH**

**ULTRASONIC PULSE VELOCITY**

**Advantages**
- Nondestructive
- Rapid and easy to perform

**Disadvantages**
- Access to both sides of member
- UPV affected by many factors besides strength
CORING

CORING OPERATIONS
- Power
- Water (cooling)
  - may have run off issues
- Access
  - Interference
  - Steel
- Repair

METAL LOCATORS
WHEN NEEDED
Can be difficult with critical members (columns, decorative concrete, precast)
Cores not necessarily required often perceived as “definitive”

CORING PLAN
- The Design Engineer must identify the location of the cores
At least 3 cores for each non-conforming test
Wipe dry, store in plastic bag until tested,
    test: 5 day minimum   adj for l/d

PLANNING CONSIDERATIONS
slightly irregular surface - needs to be removed
need l/d > 1
Analysis of Cores
ACI 301-1.6.4.3
interpretation: IF
lowest core strength ≥ 75% of $f'_c$
AND average of all cores ≥ 85% of $f'$
Example: $f'_c = 4000$ psi:
core 1 = 3720 psi
core 2 = 3190 psi
core 3 = 3640 psi
avg = 3516 psi
75% of 4000 = 3000
85% of 4000 = 3400
OK OK
interpretation:
IF lowest core strength ≥ 75% of $f'_c$
AND average of all cores ≥ 85% of $f'$
Core tests showed that this member is:
"structurally adequate"
WHAT REBOUND HAMMER CAN BE USED TO DETERMINE:
REBOUND HAMMER MOST COMMON METHOD
Area to be cored to test strength.
ESTIMATE CONCRETE STRENGTH

- Test members (beams, panels) that has acceptable strength made with same mixture design
- Test member that has unknown strength
- If approximately the same, the strength would be considered approximately the same

REBOUND HAMMER MUST BE CALIBRATED TO CONCRETE CORES FROM SAME PROJECT

Since coring of precast members can cause damage, the engineer may allow comparison of strength to concrete cylinders.

CALIBRATING THE REBOUND HAMMER

ACCURACY FOR DETERMINING STRENGTH
- Reported to be 70-95%.
- If use cylinders/cores accuracy can be 80-95%
REBOUND HAMMER NEEDS TO BE PERIODICALLY CALIBRATED AND OILED.

WHY CALIBRATION IS NECESSARY
- Hammer stored with spring under compression
- Parts wear
- Operators change

IF YOU ARE PAYING FOR NDT OR TRY TO PROVE A POINT – MAKE SURE IT IS DONE RIGHT

ASTM C 805
- Test only on concrete that is at least 4 inches thick
- Avoid honeycombing, soft spots
- Must have smooth surfaces
- Do not test frozen concrete

ASTM C 805, CONTINUED
- Do not compare ground to un-ground surface
- Hold rebound hammer perpendicular
- Keep readings 1 inch apart.
ASTM C 805, CONTINUED

- Take 10 readings
- Discard a reading that varies more than 6 units from average
- If 2 readings vary by more than 6 units, discard all readings and redo test

ACI 301-1.6.4.2

- NDT (Rebound Hammer) may be permitted to determine uniformity and locations of areas to be cored.
- These methods shall not be used to evaluate in-place strength.

CAUTION BEFORE USING REBOUND HAMMER

- Make sure designer/building official/owner understands what you are doing

Before beginning a Rebound Hammer Testing Program

- How do I plan to use the results? What do I hope to prove?
- Is the operator experienced?
- Will ASTM C 805 be used?

QUESTIONS

CAUTION BEFORE USING REBOUND HAMMER