Best Construction and Maintenance Practices for Long-Term Durability

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Construction and Longevity

• Choosing the right ingredients and the right recipe are important to make a great meal…

• …but everything still needs to be cooked properly!
Construction and Longevity

• Mix design and proportioning are important for achieving long-term durability, but the construction process just as crucial to making sure a concrete structure meets its design goals.

Steps to Long Life

- **Target performance**
  - Workability – response to handling / vibration as needed
  - Durability – survive the environment
  - Strength – enough

- **Design Levers**
  - Gradation – Tarantula Curve
  - Paste Volume – Fill void space + a bit
  - Cementitious – w/cm, SCMs
  - Admixtures – AVS, flow, bleed rate

- **Batching**
  - Uniformity – Water control
  - Cementitious blending
  - Adjustments for incoming variability
  - Mixing – Time and energy

- **Transport**
  - Mixing – equipment used
  - Workability
    - Time and weather
    - Added water / admixtures
  - Segregation – mixture

- **Placement**
  - Workability – Time and equipment
  - Air-void-system – pumping, vibration, finishing
  - Uniformity – Handling and vibration

- **Finishing**
  - Surface – air, bleeding, weather, setting time, smoothness
  - Curing – methods, duration
  - Sawing – Timing, equipment

Construction Practices are Critical to Longevity

• Disruptions in delivery and placement can lead to cold joints.
### Construction Practices are Critical to Longevity

- Over-vibration can lead to surface defects and segregation:

![Image: Minnich](image1)

- Improper finishing can lead to delamination and scaling:

![Images: PCA](image2)

- Late joint sawing can lead to random cracking:

![Image](image3)

### CP Tech Center Programs

- Integrated Materials and Construction Practices Manual:

![Image](image4)
CP Tech Center Programs

- Performance Engineered Concrete Paving Mixtures (PEM)
  - Developing better tools to design, specify, and measure important properties of concrete pavement mixes

**Incoming Data**

![Image: Oklahoma State University]

Next steps:
- Performance Centered Concrete Construction
  - Addressing everything between the batch plant and the grade that influences concrete durability and performance
    - Batching
    - Transport
    - Handling
    - Placement
    - Consolidation
    - Finishing
    - Curing
    - Sawing

Batching

- The batching and mixing process can introduce significant variability to concrete production
  - Dry batch vs. central batch
  - Timing and uniformity of addition of materials, admixtures

**Batching**

- Things to watch for handling aggregates:
  - Segregation
  - Moisture content

**Incoming Data**
**Batching**

- Variations in aggregate gradation and moisture content from mix-to-mix can cause swings in concrete uniformity and workability.
- If this causes difficulty with placement, consolidation, finishing, etc., it can lead to durability problems down the line.

**Batching**

- How can we address variability that stems from the batching process?
  - Monitor aggregate moisture contents and make mix adjustments.
  - Test early and often for concrete uniformity and report back to the plant.
  - Can we develop better testing tools to measure uniformity?
    - Long-term goal: integrate them in real-time with the construction process.

**Transport**

- Timing and consistency of delivery from the plant to the site can be affected by:
  - Weather
  - Traffic
  - Site Conditions
  - Workforce

**Transport**

- Potential downstream effects of disruptions in transportation:
  - Varying workability and uniformity
  - Mix can fall out of temperature specification
  - Need for water and admixture additions on-site
  - Changes to pump pressure, vibration frequency
  - Cold joints in structures
  - Paving machine stops and starts
Transport

- New QC tools can help producers and contractors keep track of adjustments made in transport and when arriving on-site
- Eventually, better sensors and test methods could be integrated with mixing and placement processes to allow for automated adjustments

Handling and Placement

- Workability of the concrete delivered to the project site needs to meet the needs of each placement method
- Aim for uniform delivery and avoid mishandling concrete in ways that change the properties of the material delivered to the site – segregation, air content, water content, etc.

Placement

- Make sure standing water is moved or displaced from inside forms and that forms will not absorb water
- Use best practices to avoid segregation
  - Don't allow concrete to pile up so that you’re forced to spread it out by hand across the deck/grade, into corners, etc.

Pavements and Slabs on Ground

- Subgrade and subbase preparation
  - Ensure stable, adequate, and uniform support
  - Settlement cracking can drive future durability issues
  - Moisten subgrade to prevent absorption of mix water
- Follow best practices for installation of vapor retarders and insulation to prevent moisture damage to floor coverings
Pumping

- Pumping has developed into one of the most common methods for concrete placement
- Common to observe a loss of air content after pumping
  - 0.5% to 1% is common – but it’s sometimes worse
  - Factors that appear to worsen air loss:
    - Higher pump pressures
    - Flowable mixtures
    - Vertical boom configurations
    - Sharp elbows in the boom configuration
  - Smaller (entrained) air bubbles should be more resilient
  - Current research working toward a better understanding of this phenomenon

Consolidation

- Proper consolidation is needed to ensure durable concrete in-place
- How much do we need?
  - Enough to achieve sufficient embedment and bond between concrete and reinforcement
  - Enough to eliminate voids and release entrapped air
  - Not so much that the entrained air is knocked out
- Vibration is the most widely-used consolidation method

Vibration

- Vibration energy is a function of:
  - Frequency
  - Amplitude
  - Duration
  - Spacing
- The energy you need to impart depends on:
  - Workability
  - Air void system
- Consequences of under-vibration
  - High entrapped air content
  - Honeycombing
- Consequences of over-vibration
  - Removal of entrained air
  - Separation of water from aggregate
    - Segregation
    - Excessive bleed water
  - Surface discoloration
  - Surface defects
Vibration

- Standard workability tests like the slump cone don’t always give us good insight into how a concrete mix responds to vibration
- VKelly test:
  - A better measure of uniformity and workability under vibration
  - Currently developed for paving mixtures

Air Void System

- The air void system can be affected by nearly every stage of the construction process:
  - Transport
  - Handling
  - Pumping
  - Vibration
  - Finishing
- If the air void system isn’t dialed in, it can also disrupt batching and the construction process!

Air Void System

- Remember what we want from our air void system
  - Small, uniform, well-distributed air bubbles that help protect against freeze-thaw damage and scaling
  - Testing at both the plant and project site can help detect problems and allow for timely adjustments at the plant
  - Behind the paving machine, after pumping...

Air Void System

- The Super Air Meter provides insight into the distribution of our air void system beyond total air content
- Future: will it be possible to make real-time, non-destructive air content measurements and make rapid adjustments?
Finishing

• Proper finishing in flatwork, exterior concrete, and pavements is important to achieve a durable, long-lasting surface.

Images: PCA, The Constructor

Finishing

• Delamination or scaling may result from:
  • Finishing while bleed water is present at the surface
  • Hard troweling of air-entrained concrete
  • Overworking the surface

Images: PCA

Finishing

• Pavements
  • Things are working best when:
    • Finishing is mostly achieved by the paving machine
    • Finishers are focused primarily on correcting minor imperfections and voids
    • No water is added to the surface to finish
    • Real-time smoothness monitoring

Images: PCA, The Constructor

Curing

• Curing has a significant influence on the final properties of concrete
  • Strength
  • Shrinkage
  • Surface properties
  • Transport properties
  • Durability

Images: PCA, The Constructor

Graph: Effect of curing time on strength gain of concrete (Gutierrez and Shanen 1986)
Curing

- What do we need to do?
  - Keep the concrete wet and warm (but not too warm) to allow hydration to proceed to its fullest extent
  - Prevent evaporation of moisture from exposed surfaces
  - Ensure complete and uniform coverage
- Things to watch out for:
  - Harsh weather conditions, e.g. cold, wind, sun
  - Changing weather patterns

Curing

- Durability issues that may result from insufficient curing:
  - Plastic shrinkage and drying shrinkage cracking
  - Undesirable surface properties (e.g. scaling, crazing, dusting, abrasion resistance)
  - Susceptibility to freeze-thaw damage and other distresses driven by water infiltration like ASR

Internal Curing

- Introduction of additional moisture to assist with curing from within the mix

Internal Curing

- Promising results reducing shrinkage cracking in bridge decks
- Reduction in temperature and moisture gradients in pavements
Internal Curing

- Most projects in the U.S. to date have used expanded lightweight fine aggregate
- Recent work is evaluating use of super absorbent polymers

Joint Sawing

- Joints are where exterior concrete slabs and pavements are most susceptible to infiltration of water and de-icing chemicals
- It's crucial to saw cut joints at the proper time and depth to ensure good performance and durability of the system
Joint Sawing

- Raveling:

  A. UNACCEPTABLE RAVELING - Issued too early
  B. MODERATE RAVELING - Issued early in weather
  C. NO RAVELING - Issued late in weather

Joint Sawing

- Be conscious of how weather and mix factors affect the sawing window
  - Weather can be unpredictable, and some mixes may be more susceptible to changes depending on the conditions
  - Hour-to-hour and day-to-day

  Weather:
  - Rising and falling temperatures
  - Sunny/cloudy
  - Wind
  - Humidity

  Mix:
  - Cementitious content and composition
  - SCMs, etc.)
  - Water demand
  - High early strength

Joint Sawing

- HIPERPAV
  - Software designed to help predict susceptibility to early age cracking based on mix design factors, weather conditions

Next Steps and Future Goals

- With a better understanding of how our construction processes affect the concrete mix, we can:
  - Gain insight into the variability introduced at each stage in concrete batching, transport and placement
  - Use measurements at the plant and at the job site to make real-time adjustments during the project
  - Leverage improved tools and technologies to create a feedback loop between production and construction
Next Steps and Future Goals

- Develop the best practices, guidance, and tools to make sure our durable concrete mix designs become durable concrete structures in-place:

Maintenance and Longevity

- Designed and constructed correctly, concrete buildings and infrastructure are capable of fulfilling very long-term service life

- Regular maintenance can go a long way to ensure that concrete meets or even exceeds its design life
- Timely maintenance and rehabilitation can also help make sure that early problems don’t compromise the life of a structure
Concrete Structures

- Corrosion of reinforced concrete

Concrete Structures

- Corrosion culprits: chlorides, carbonation, and time

As a structure ages, carbonates, etc., there are proactive measures that can be taken to delay the onset of corrosion:
- Keep water and chlorides out!
  - Penetrating surface sealers
  - Water repellent coatings
  - Overlays
  - Seal cracks

Concrete Structures

- Preservation of structures already experiencing corrosion damage is possible through several methods:
  - Corrosion inhibitors
  - Cathodic protection
  - Electrochemical chloride migration
Pavements and Exterior Concrete

- Concrete structures and surfaces exposed to the elements face some of the harshest durability challenges
  - Moisture
  - Freeze-thaw cycles
  - De-icing chemicals

Protection from Water and De-icing Salts

- Freeze-thaw damage occurs when concrete becomes critically saturated and temperatures drop below freezing
  - Exposed joint faces are most susceptible to saturation
  - Infiltration of de-icing chemicals will also occur at joints

Protection from Water and De-icing Salts

- De-icing chemicals are an issue for multiple reasons:
  - They like to hang onto water and keep the concrete saturated

De-icing chemicals are an issue for multiple reasons:
- They directly react with calcium hydroxide within the concrete microstructure itself to produce oxychlorides
  - Expansion nearly 3× greater than that of water freezing!

\[ 3\text{Ca(OH)}_2 + \text{CaCl}_2 + 12\text{H}_2\text{O} \rightarrow \text{CaCl}_2 \cdot 3\text{Ca(OH)}_2 \cdot 12\text{H}_2\text{O} \]

Calcium Oxychloride
### Maintenance Practices
- Joints are where exterior concrete slabs and pavements are most susceptible to infiltration of water and de-icing chemicals.
- Properly designing and proportioning the mixture is critical to reducing the susceptibility of concrete to joint deterioration.
- Even if you have a pavement that is susceptible to this type of damage, or starting to experience it, there are maintenance and preservation activities to repair, slow, and prevent further damage.

### Joint Sealing/Filling
- It's never too late to clean out and seal (or re-seal) joints.
- Joint sealing vs. filling with hot pour asphalt sealant.
- Backer rod is no longer recommended.

### Joint Rehabilitation
- Before joint deterioration gets too bad…
- …it can still be repaired and restored through partial depth patching.
Surface Sealers

- Another option when pavements appear susceptible to joint deterioration is to apply a breathable, penetrating surface sealer. Laboratory test protocol for evaluating the suitability of surface sealers for pavement joints published this year:

Winter Maintenance

- Concrete can stand up to de-icing challenges when we use a good mix, good construction practices, and proper maintenance.
- One thing to keep in mind: what about the first winter?
  - Concrete placed before the fall should be fine.
  - What about late season placements in climates where temperatures start to drop in the fall?
    - Curing and hydration can slow quite a bit in the short-to-medium term.
    - Mixes with greater SCM replacement rates are generally more sensitive to falling temperatures.

- Options for the first winter:
  - Less harsh de-icing treatments
    - Sand (if possible)
    - Stick to sodium chloride ("regular salt")
  - More judicious applications: less brine and pre-treatment
  - Apply a penetrating sealer to the surface/joints
  - Be mindful of application temperature